KAMALA D. HARRIS
Attorney General of California
GAVIN MCCABE, State Bar No. 130864
Supervising Deputy Attorney General
ALLISON GOLDSMITH, State Bar No 238263
CLIFFORD T. LEE, State Bar No. 74687
Deputy Attorneys General
455 Golden Gate Avenue, Suite 11000
San Francisco, CA 94102-7004
Telephone: (415) 703-5546
Fax: (415) 703-5480
E-mail: Clifford.Lee@doj.ca.gov
Attorneys for Plaintiff-Intervenor
California Department of Water Resources

IN THE UNITED STATES DISTRICT COURT

FOR THE EASTERN DISTRICT OF CALIFORNIA

THE CONSOLIDATED DELTA SMELT CASES	Lead Case: 1:09-cv-407-LJO-BAM Member Cases: 1:09-cv-422-LJO-DLB 1:09-cv-631-LJO-DLB 1:09-cv-892-LJO-GSA Partially Consolidated With: 1:09-cv-480-LJO-GSA 1:09-cv-1201-LJO-DLB **DECLARATION OF LAURA KING MOON IN SUPPORT OF REQUEST TO FURTHER EXTEND REMAND SCHEDULE**
THE CONSOLIDATED SALMONID CASES	Lead Case: 1:09-cv-1053-LJO- BAM Member Cases: 1:09-cv-1090-LJO-DLB 1:09-cv-1378-LJO-DLB 1:09-cv-1520-LJO-DLB 1:09-cv-1580-LJO-DLB 1:09-cv-1625-LJO-SMS **DECLARATION OF LAURA KING MOON IN SUPPORT OF REQUEST TO FURTHER EXTEND REMAND SCHEDULE**

I, Laura King Moon, declare that:

1. I am the Chief Deputy Director of the Plaintiff-Intervenor California Department of Water Resources (DWR). I hold degrees in Conservation of Natural Resources and Energy and Resources, including a Master of Science degree from the University of California at Berkeley. Prior to my appointment as Chief Deputy Director on September 18, 2013, I served as Assistant General Manager for the State Water Contractors for over ten years. In that capacity I served as the project manager for the Bay Delta Conservation Plan, beginning in 2006, with my last two years of service in that position on loan to the Department of Water Resources. In my current capacity as Chief Deputy Director, I oversee work performed by Department staff with the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS) and the U.S. Bureau of Reclamation (BOR) in the implementation of the delta smelt and salmonid biological opinions, on the Bay Delta Conservation Plan, and serve as DWR's representative on the Collaborative Adaptive Management Team.

2. I have reviewed the Second Declaration of Dale Hoffman-Floerke submitted in the *Consolidated Salmonid Cases*, Lead Case No. 1:09-cv-1053 LJO-DLB (Doc. 731-1) and in the *Delta Smelt Consolidated Cases,* Lead Case No. 1:09-cv-407 LJO-DLB (Doc. 1101-1). DWR filed that in support of the DWR and Federal Defendants' March 15, 2013 joint motion to extend the remand schedule in the Salmon BiOp and the Smelt BiOp cases. In that declaration, DWR identified collaborative scientific efforts that would assist in protecting fishery resources that would benefit from extensions to the Salmon BiOp and the Smelt BiOp remand schedules. These collaborative scientific research efforts fell into four categories: science regarding the fall outflow related to the X2 Reasonable and Prudent Alternative (RPA), studies of turbidity triggers which give warning of smelt presence near the federal and state projects' intakes, development of life cycle models for smelt and salmonids, and further scientific studies to improve the understanding of salmonid survival. The following will describe progress that has occurred in these collaborative endeavors since the filing of the joint motion.

Fall Outflow Science Related to the X2 RPA

3. The Interagency Ecological Program (IEP) for the San Francisco Bay / Sacramento-San Joaquin Estuary is a collaborative effort consisting of ten member agencies; three State (DWR, Department of Fish and Wildlife, and State Water Resources Control Board), six Federal (USFWS, BOR, Geological Survey, Army Corps of Engineers, NMFS, and Environmental Protection Agency), and one non-government organization (The San Francisco Estuary Institute). These ten program partners work to develop a better understanding of the estuary′s ecology and the effects of the State Water Project (SWP) and Federal Central Valley Project (CVP) operations on the physical, chemical, and biological conditions of the San Francisco Bay-Delta estuary. In 2012, the U.S. Geological Survey, in cooperation with the BOR and the IEP, issued a draft report on fall low salinity habitat for the delta smelt (FLaSH). The purpose of the study was to explore hypotheses about the ecological role of fall low salinity habitat in the San Francisco Estuary. An independent scientific review panel has peer reviewed the draft FLaSH report. It is anticipated that a final report will be issued in 2014. In addition to developing questions and workplans regarding Fall X2 studies, the Collaborative Adaptive Management Team's Progress Report to the Collaborative Science Policy Group (Progress Report) builds on the draft FLaSH study report and identifies 31 ongoing or recently completed FLaSH studies related to the delta smelt. Rea Decl., Ex. A (Progress Report, Table 5-1.)

Development of Turbidity Triggers for Smelt Protection

4. In addition to the work described in the Progress Report regarding turbidity, the Metropolitan Water District of Southern California (MWD) has recalibrated a DWR hydrology model known as DSM2 to simulate Delta turbidity. In November of 2013, MWD provided the model to DWR's Operations Control Office staff for regular use. In reviewing the modeling results, Operation Control Office staff have determined that the model is useful for forecasting and following the "first flush" turbidity movement at certain locations within the Delta. DWR staff have determined that the DSM2 turbidity model and a second model known as the Watershed Analysis Risk Management Framework (WARMF) model are useful in forecasting the

"first flush," thus predicting the timing, location, and, to some degree, level of the initial entrance of turbidity into the Delta in a real-time time frame. Though WARMF has been available for a few years, DWR's ability to use the model in a real-time time frame is a recent development.

5. DWR's Operations Control Office staff and the federal agencies have been coordinating on these modeling tools. In addition, the Delta Conditions Team meets weekly and includes representatives from MWD, NMFS, USFWS, DFW, DWR, BOR, Contra Costa Water District and others. Both the turbidity model and the WARMF model results have been shared within the Delta Conditions Team. Operations Control Office staff are working with members of the Delta Conditions Team to develop improved visualization and distribution methods for the modeling results. Beginning in early December, Operations Control Office staff have been performing turbidity modeling runs, but due to the extremely dry conditions in Water Year 2014 (prior to precipitation events in early February), this modeling has not been useful or relevant to the Delta Conditions Team discussions. However, Operations Control Office staff will continue to run the turbidity model and will make the results available for discussion at the next and subsequent Delta Conditions Team meetings.

Science to Improve Understanding of Salmonid Survival

6. The Progress Report describes the CAMT scientific efforts directed at improving the understanding of salmonid survival. These efforts include the work completed and planned by the South Delta Salmon Research Collaborative.

7. In addition, on February 7, 2014, DWR released the final report containing the results of 2012 acoustic tagging and release program required by the 2012 Joint Stipulation regarding CVP and SWP Operations. Final Report of the 2012 Stipulation Study of Salmonid Migration (Feb. 7, 2014), attached as Exhibit A. In implementing this requirement, DWR, in collaboration with BOR, the USFWS, the U.S. Geological Survey, and SWP and CVP water contractors, conducted a mark and recapture experiment to examine the survival and movement patterns of acoustically tagged juvenile steelhead emigrating through the central and southern Delta. This field experiment implemented different Old and Middle River (OMR) flow levels for

three two-week periods when acoustically tagged steelhead were used to gather information about the responses of tagged fish to different hydrodynamic conditions. The study results addressed the predictive value of the Delta Simulation Model II, Particle Tracking Model as to the movement of steelhead tags, analyzed the specific travel paths or routes taken by the tagged fish, their survival rates, travel times, and other variables, and assessed the influence of a range of OMR flows on the routing of steelhead at the Columbia Cut, Middle River, and Turner Cut junctions along the San Joaquin River. These study results directly address issues raised regarding some of the RPA actions in the Salmon BiOp, and will be reviewed by the CAMT and the Federal Defendants.

Development of Life Cycle Models for Delta Smelt and Salmonids

8. In addition to the life cycle model discussion contained in the Progress Report, the IEP has developed a new conceptual model of the complete life cycle of the delta smelt based on historical and new analyses through its Management, Analysis and Synthesis Team (MAST). IEP issued the draft MAST report on July 23, 2013. It is anticipated that the MAST report will become final in 2014.

9. The Collaborative Science Adaptive Management Program anticipated establishing a modeling group, which could serve as a forum for exchange of information about the development, structure and use of life cycle models for both delta smelt and salmonids, with the objective of transparency. Delta Smelt life cycle model information from the IEP, undertaken by Ken Newman (USFWS), would build a life cycle model combining the current knowledge of the species life history with the extensive trawl survey data on distribution and abundance of delta smelt. Phase 1 of this effort will develop a life history model for delta smelt, and Phase 2 will either develop multiple single species life history models for one or more fish species, or a single integrated multi- species life history model. A presentation of Newman's delta smelt life cycle model work was given to the IEP in May 2013. The model reached a milestone state of development and a first publication is in preparation. In addition, USFWS has hired a post- doc, Leo Polansky, for a minimum of 2 years, to provide technical assistance with ongoing

preliminary exploratory data analysis, state–space model formulation, and model fitting. Also in May 2013, Dr. Newman began collaborative work with David Fullerton (MWD) and Mark Maunder (Inter-American Tropical Tuna Commission), with the latter providing technical assistance with model fitting using AD Model Builder.

I declare under penalty of perjury that the foregoing is true and correct, and that his declaration is executed this 18th day of February, 2014 at Sacramento, California.

Laura King Moon

EXHIBIT A

State of California
The California Natural Resources Agency
Department of Water Resources

Stipulation Study: Steelhead Movement and Survival in the South Delta with Adaptive Management of Old and Middle River Flows

Prepared by
David Delaney, Paul Bergman, Brad Cavallo, and Jenny Melgo
Cramer Fish Sciences
13300 New Airport Road, Suite 102
Auburn, CA 95602

Under the direction of:
Kevin Clark
Bay-Delta Office
Biotelemetry and Special Investigations Unit

February 2014

Edmund G. Brown, Jr. Governor State of California	**John Laird** Secretary for Natural Resources California Natural Resources Agency	**Mark W. Cowin** Director Department of Water Resources

State of California
Edmund G. Brown, Jr., Governor

California Natural Resources Agency
John Laird, Secretary for Natural Resources

Department of Water Resources
Mark W. Cowin, Director

Laura K. Moon
Chief Deputy Director

Kasey Schimke
Asst. Director Legislative Affairs

Nancy Vogel
Asst. Director Public Affairs

Cathy Crothers
Chief Counsel

Gary Bardini
Deputy Director
Integrated Water Management

Paul Helliker
Deputy Director
Delta/Statewide Water Management

Kathie Kishaba
Deputy Director
Business Operations

John Pacheco
Deputy Director
California Energy Resources Scheduling

Carl Torgersen
Deputy Director
State Water Project

Katherine Kelly

Chief, Bay-Delta Office

Victor Pacheco

Chief, Delta Conveyance Branch

Matthew Reeve

Chief, Delta Conveyance Fish Science Section

California Department of Water Resources

1416 9th Street, Sacramento, CA 95814, USA

EXECUTIVE SUMMARY

Juvenile steelhead (*Oncorhynchus mykiss*) migrating downstream in the San Joaquin River are vulnerable to mortality from a variety of stressors. Two of these stressors are entrainment and predation (entrainment at State Water Project [SWP] and federal Central Valley Project [CVP] facilities, and exposure to predation within the Sacramento-San Joaquin Delta [Delta] and predation near and associated with the two facilities). The SWP and CVP facilities are south of the confluence of the San Joaquin and Sacramento rivers. Export of water can change the flow dynamics in the central and south Delta (e.g., Old and Middle River [OMR] reverse flows, flows passing into Old River, etc.). All OMR flows referred to in this report are average daily values. The hydrodynamic changes have been hypothesized to result in altered migration pathways, migration delays, and other indirect effects that contribute to reduced survival of juvenile salmonids passing through the lower San Joaquin River and Delta. To protect fish, SWP and CVP export rates in the late winter and spring months have been regulated to reduce the magnitude of OMR reverse flows.

Current management actions are calendar and trigger based during the period when Endangered Species Act (ESA)-listed salmonids are present in the Delta. Triggers are based, in part, on rates of entrainment of fish at the SWP and CVP. If salmonid protection measures could be implemented based on fish presence farther from the export facilities, it is hypothesized that: (1) the direct and indirect risks to salmonids associated with the export facilities may be reduced, and measurement of take at SWP and CVP facilities can be replaced with other metrics for reducing impacts from the water projects; and (2) exposure of ESA-listed salmonids to predation in the south Delta channels can be reduced.

On January 12, 2012, Plaintiffs, Plaintiff-Intervener, and Federal Defendants to the Consolidated Salmonid Cases (Case 1: 09-cv-Ol 053-LJO-DLB) signed and filed a Joint Stipulation (Document 659-2; Attachment 1 in NMFS 2012) that specified a collaborative acoustic tag study for steelhead and CVP and SWP operations for April and May 2012 (NMFS 2012). The three objectives for the 2012 Stipulation Study were to:

(1) Evaluate potential effects of OMR flows during April and May on the survival, migration rate, and net migration direction of acoustically tagged juvenile steelhead in the Delta.

(2) Estimate the route entrainment of acoustically tagged juvenile steelhead in the Delta under different tidal conditions and OMR flows.

(3) Provide daily and weekly steelhead tag detection data that could be used to adaptively manage OMR flows within the adaptive range specified in the Joint Stipulation.

To address the Joint Stipulation objectives, in the spring of 2012, a mark-recapture experiment was implemented by the California Department of Water Resources (the Department) and its contractors, with collaboration from the United States Bureau of Reclamation (Reclamation), United States Fish and Wildlife Service (USFWS), and United States Geological Survey (USGS) to examine the survival and movement patterns of acoustically tagged juvenile steelhead emigrating through the central and southern Delta. This field experiment implemented different OMR flow levels for three, 2-week release periods when acoustically tagged steelhead were used to gather information about the responses of tagged fish to different hydrodynamic conditions. During the study, the Head of Old River Barrier (HORB) was in place, which prevented flow from entering the interior Delta through Old River and directed flow along the Mainstem San Joaquin River. Included in the study was an “exposure trigger” that, if reached or exceeded, shifted operations from the experimental OMR flow level to the least negative OMR flow level within the adaptive range. This was intended to protect naturally produced steelhead migrating through the Delta by shifting hydrodynamic conditions in a direction that may be less disruptive to outmigration routing while simultaneously allowing investigation of the response of steelhead tags to changes in OMR flow levels. This “Railroad Cut trigger” was calculated as 5% of the release group reaching the acoustic receiver arrays at Railroad Cut, under the assumption that 5% of fish arriving at Railroad Cut would be expected to result in a 2% loss of the release group at the fish collection facilities (NMFS 2012).

The original experimental design called for each 2-week experimental period to represent one of three OMR reverse flow magnitude targets (-1,250, -3,500, and -5,000 cubic feet per second [cfs]). Average observed OMR flows during the first 7 days following release were -2,446, -2,933, and -5,038 cfs for Release Groups 1, 2, and 3, respectively. Near-real-time monitoring (i.e., daily data collection) of detections of steelhead tags at Railroad Cut exceeded the trigger and caused OMR flow modifications during each experimental period.

Every 2 weeks, acoustically tagged juvenile steelhead were released at regular intervals over 24 hours at Buckley Cove in the lower San Joaquin River. In total, 166, 167, and 168 acoustic coded transmitters (VEMCO, model V6-4X) were functioning in live steelhead for release groups (Group 1, 2, or 3) when released on April 15-16, May 1-2, and May 15-16, 2012, respectively. Tag detection data were collected from 15 acoustic receiver arrays deployed for this study and nine acoustic receiver arrays deployed for the Six-Year Steelhead Study (Six-Year Study). The release groups acted as a surrogate for the average OMR flow conditions that occurred during the three study periods. The release groups experienced an "OMR treatment" measured as the average OMR flows during the first 7 days of each study period. Based on a recommendation in the 2012 Independent Review Panel (IRP) on the Long-term Operations Opinions (LOO) Annual Review, we also pooled the data from Release Groups 1 and 2 and hereafter referred to as the less negative OMR flow treatment because OMR flow levels were similar during these two time periods. We then compared this less negative OMR flow treatment group to the more negative OMR flow treatment level experienced by Release Group 3. The data were examined using both qualitative, descriptive analyses and quantitative, statistical hypothesis-testing analyses. The analyses were separated into three report sections based on the spatial level ranging from system, route, and junction-level discussion.

SYSTEM-WIDE LEVEL RESULTS

System-wide results are those that focus on the large-scale movement patterns across the Delta. The quantitative statistical analyses determined that a physically based model in the form of the Delta Simulation Model II (DSM2) Hydro Particle Tracking Model (PTM) was not able to predict the movement of steelhead tags. The model greatly underestimated the steelhead tag movement rate through the study area. Steelhead tags were traveling significantly greater distances than passive particles 3 days and 7 days after their release. Steelhead have a complex set of behaviors and respond to both biotic and abiotic factors that can affect where and how fast they migrate. Further investigation indicated that tags deployed in juvenile steelhead exhibited limited selective tidal-stream transport (STST) movement patterns, which could explain why steelhead tags moved far faster than passive particles. This was likely the result of steelhead tags being transported by ebbing tides while holding position on flood tides. This investigation revealed that overall, there seemed to be some evidence that steelhead tags were being transported more during the night in the Mainstem San Joaquin River, while more steelhead tags were being transported during the day at some interior Delta arrays.

ROUTE-LEVEL RESULTS

Route-level analysis refers to the specific travel pathways (routes) that fish can take from one point to another, and the survival rates, travel times, and other variables resulting from these different routes. We examined if the route-specific survival probabilities, transition probabilities (a measure of steelhead tags that went through a route and survived), and travel times for steelhead tags varied between the routes taken and, where possible, between release groups. Data from the release groups used in the model were pooled, but the individual release group data were used to estimate travel times and subsequent travel time analysis.

A multistate model was built to evaluate route-specific transition probabilities, survival probabilities, and detection probabilities of steelhead tags. This model allowed us to estimate route-specific transition probability for each of the six different routes (all routes started downstream of Buckley Cove and ended at Chipps Island):

- The route-specific probability via Turner Cut was 7.0% (standard error [SE]=1.6%).
- The route-specific probability without using Turner Cut was 24.8% (SE=2.0%).

- The route-specific probability via Turner Cut and the SWP was 0.5% (SE=0.5%).
- The route-specific probability via the SWP without using Turner Cut was 0.2% (SE=0.2%).
- The route-specific probability via Turner Cut and the CVP was 19.6% (SE=2.8%).
- The route-specific probability via CVP without using Turner Cut was 31.7% (SE=1.9%).

When combined, the model indicated that most steelhead tags remained in the Mainstem San Joaquin River (77.6%); however, approximately one quarter (22.4%) of them entered Turner Cut. The overall survival was 50.2% (SE=2.0%) for all routes combined. Route-specific survival probability for steelhead tags using the Turner Cut route was 27.0% (SE=3.0%). The survival probability for steelhead tags using the Mainstem route was 56.7% (SE=2.4%).

In an analysis outside of the model, we found that travel times for steelhead tags differed between these two routes. Steelhead tags that used the Mainstem route reached Chipps Island significantly sooner than those that used the Turner Cut route. This result remained valid for all three release groups and when Groups 1 and 2 were combined. Travel time was not significantly affected by the OMR flow treatments examined in this study.

JUNCTION-LEVEL RESULTS

The junction-level analysis specifically looked at three locations in the Delta to evaluate the influence of OMR flows on steelhead tag movement at these locations. There was no evidence that the routing of steelhead tags at the Columbia Cut, Middle River, and Turner Cut junctions along the San Joaquin River was affected by the OMR flow treatments examined in this study. When the data were examined using two release groups (less negative vs. more negative OMR flows), we found no significant differences in routing of the steelhead tags. While not significant, there was some evidence that fish movement toward each export facility could be influenced by relative flow entering the export facility.

One of the goals of this study was to determine whether steelhead tags at Railroad Cut were more likely to move away from the SWP and CVP intakes (north) after the adaptive management option triggered less negative OMR flows. This could not be completed in a statistically valid manner because of the small sample size (N=7) of steelhead tags passing through Railroad Cut after the effect of the management action was observed (OMR flows reached -1,250 cfs). However, there was marginally significant evidence that steelhead tags at Railroad Cut were more likely to move north under less negative (Groups 1 and 2) OMR flows than in more negative (Group 3) OMR flow conditions. We examined nine predictor variables in separate tests. Only the test that used average OMR flow on the day that the steelhead tag was first detected downstream of Railroad Cut was found to be significant.

CONCLUSIONS

The overarching objectives for this study were to evaluate the effects of OMR flows on survival, migration rate, and migration direction; estimate route selection under different OMR flow conditions; and provide steelhead tag detection data that could be used to adaptively manage OMR flows. The quantitative statistical analyses determined that the DSM2 Hydro PTM was not able to predict the movement of steelhead tags because the model greatly underestimated steelhead tag movement through the study area. We found that diurnal and nocturnal movement patterns of steelhead tags might be occurring, but these patterns were location-specific and worthy of future study.

Under the OMR flow treatments tested in this study, there appeared to be little influence of OMR flows tested on steelhead tag travel times on the route-level and steelhead tag movement at the junctions and routes examined in this study. There was limited evidence of an influence of OMR flows on steelhead tag routing at Railroad Cut to the south and the export facilities; sample size limited our ability to be more specific. More than 90% of steelhead tags passed the detection point at Railroad Cut before the less negative OMR flow conditions were triggered and observed to take effect.

Improvements to experimental design of future real-time monitoring studies could be made; however, this study indicated that tagged steelhead cannot effectively be used as “sentinels” to trigger export changes. There is little evidence that altering OMR flows within the range that we examined in this study would alter fish behavior in a meaningful way. The observed limited influence of OMR flows evaluated in this study on steelhead tag behavior does not support real-time monitoring as an effective tool to protect salmonids from entrainment.

This study was limited by the amount of time for its preparation and the ranges of OMR flows tested. Therefore, we recommend an additional more comprehensive study that examines a wider range of OMR flows in replicated treatments with larger samples sizes as one of the future studies.

ACKNOWLEDGEMENTS

We would like to acknowledge contributions (e.g., reviewing data analysis plans, draft of final report, and/or models) to this work from the following people in alphabetical order by last name:

Pat Brandes, United States Fish and Wildlife Service

Rebecca Buchanan, Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA

Barbara Byrne, National Oceanic and Atmospheric Administration National Marine Fisheries Service

Chuck Hanson, Hanson Environmental

Josh Israel, United States Bureau of Reclamation

Javier Miranda, California Department of Water Resources

Victor Pacheco, California Department of Water Resources

Kevin Reece, California Department of Water Resources

We would like to thank Annie Brodsky and Jenny Melgo for querying and conducting quality assurance/quality control for the data that was the basis for the analyses. Also, we would like to thank Travis Hinkelman for creating the web-based tool. We would like to thank Josh Israel for providing data on the duration of battery lives, from the 2012 battery life studies. Further, we would like to thank Josh Israel for providing data from Six-Year Study tags and acoustic receiver arrays.

Finally, we would like to thank Peter Carr and Demian Ebert at AECOM for editing and formatting the document.

This page intentionally left blank.

TABLE OF CONTENTS

Appendices

TABLE OF CONTENTS

Continued **Page**

Figures

TABLE OF CONTENTS

Continued **Page**

TABLE OF CONTENTS

Continued **Page**

Tables

TABLE OF CONTENTS

Continued **Page**

ACRONYMS AND OTHER ABBREVIATIONS

ANOVA	analysis of variance
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CFS	Cramer Fish Sciences
cfs	cubic feet per second
CHTR	Collection, Handling, Transport, and Release
cm	centimeter
CVP	Central Valley Project
Delta	Sacramento-San Joaquin Delta
Department	California Department of Water Resources
DSM2	Delta Simulation Model II
ESA	Endangered Species Act
GLM	generalized linear model
GPS	Global Positioning System
HORB	Head of Old River Barrier
HRR	high residence receiver
HTI	Hydroacoustic Technology Inc.
ID	identification
IRP	Independent Review Panel
JSATS	Juvenile Salmon Acoustic Telemetry System
kHz	kilohertz
km	kilometer
L	liter
LOO	Long-term Operations Opinions
m	meter
m/sec	meters per second
mg	milligram
mm	millimeter
MS	Microsoft
MS-222	tricane methanesolfonate
N/A	not applicable
NMFS	National Marine Fisheries Service
OMR	Old and Middle River
ppm	pulses per minute

ACRONYMS AND OTHER ABBREVIATIONS

PTM	Particle Tracking Model
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
Reclamation	United States Bureau of Reclamation
RMS	root-mean-square
RPA	Reasonable and Prudent Alternative
SE	standard error
SJR	San Joaquin River
SJRGA	San Joaquin River Group Authority
SOP	Standard Operating Procedure
STH	steelhead
STST	selective tidal-stream transport
SWP	State Water Project
TRN	Turner Cut
USER	User Specified Estimation Routine
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VAMP	Vernalis Adaptive Management Program
VUE	VEMCO User Environment

This page intentionally left blank.

1 STUDY DESCRIPTION

CHAPTER SUMMARY:

On January 12, 2012, Plaintiffs, Plaintiff-Intervener, and Federal Defendants to the Consolidated Salmonid Cases (Case 1: 09-cv-Ol 053-LJO-DLB) signed and filed a Joint Stipulation (Document 659-2) that specified Central Valley Project (CVP) and State Water Project (SWP) operations for April and May 2012, installation of the Head of Old River Barrier (HORB), and broadened acoustic tagging and release program in 2012 to track juvenile steelhead (*Oncorhynchus mykiss*) migrations through the south Sacramento-San Joaquin Delta (Delta) for the purpose of generating better information by which to manage south Delta operations and other activities to improve fish survival. The three objectives for the 2012 Stipulation Study were to:

(1) Evaluate potential effects of Old and Middle River (OMR) flows during April and May on the survival, migration rate, and net migration direction of acoustically tagged juvenile steelhead in the Delta.

(2) Estimate route entrainment of acoustically tagged juvenile steelhead in the Delta under different tidal conditions and OMR flows.

(3) Provide daily and weekly steelhead tag detection data that could be used to adaptively manage OMR flows within the adaptive range specified in the Joint Stipulation.

The 2012 Stipulation Agreement called for the operation and maintenance of an acoustic receiver array in the Delta, fish tagging and releases, adaptive management of OMR reverse flow magnitude, and data analysis and report writing. The Stipulation Study was a collaborative project that involved the California Department of Water Resources (the Department), some of its contractors (AECOM, Cramer Fish Sciences, Hanson Environmental, Inc., and Bole and Associates), United States Bureau of Reclamation (Reclamation), United States Fish and Wildlife Service (USFWS), and United States Geological Survey (USGS).

1.1 STUDY OBJECTIVES

Objectives for the 2012 Stipulation Study were to:

- Evaluate potential effects of OMR flows during April and May on the survival, migration rate, and net migration direction of acoustically tagged juvenile steelhead in the Delta.

- Estimate route entrainment of acoustically tagged juvenile steelhead in the Delta under different tidal conditions and OMR flows.

- Provide daily and weekly steelhead tag detection data that could be used to adaptively manage OMR flows within the adaptive range specified in the Joint Stipulation.

1.2 BIOLOGICAL AND REGULATORY BACKGROUND

Juvenile steelhead and Chinook salmon (*Oncorhynchus tshawytscha*) migrating downstream in the San Joaquin River are vulnerable to entrainment at the SWP and the CVP export facilities and the associated exposure to pre-screen predation mortality within Clifton Court Forebay and near the trash racks at the CVP fish collection facility. These facilities are located south of the confluence of the San Joaquin and Sacramento rivers (Figure 1-1). Thus, by the time Endangered Species Act (ESA)-listed salmonids (Central Valley steelhead and Central Valley winter-run and spring-run Chinook salmon) are detected at the salvage facilities, OMR flow changes may be enacted too late to achieve fish protection. In addition, changes in the direction and/or magnitude of flows in the central and south Delta channels (e.g., OMR reverse flows, flows passing into Old River, etc.) have been hypothesized to result in altered migration pathways, migration delays, and other indirect effects that contribute to reduced survival of juvenile salmonids passing through the lower San Joaquin River and Delta. In response to these concerns, the National Marine Fisheries Service (NMFS) included several Reasonable and Prudent Alternative (RPA) actions in the biological opinion that focused on Delta flow management during the winter and spring (NMFS 2009). SWP and CVP export rates in the late winter and spring months have been regulated to reduce the magnitude of OMR reverse flows. Action IV.2.1 of the biological opinion restricts south Delta exports in April and May to a fraction of the flow in the lower San Joaquin River.

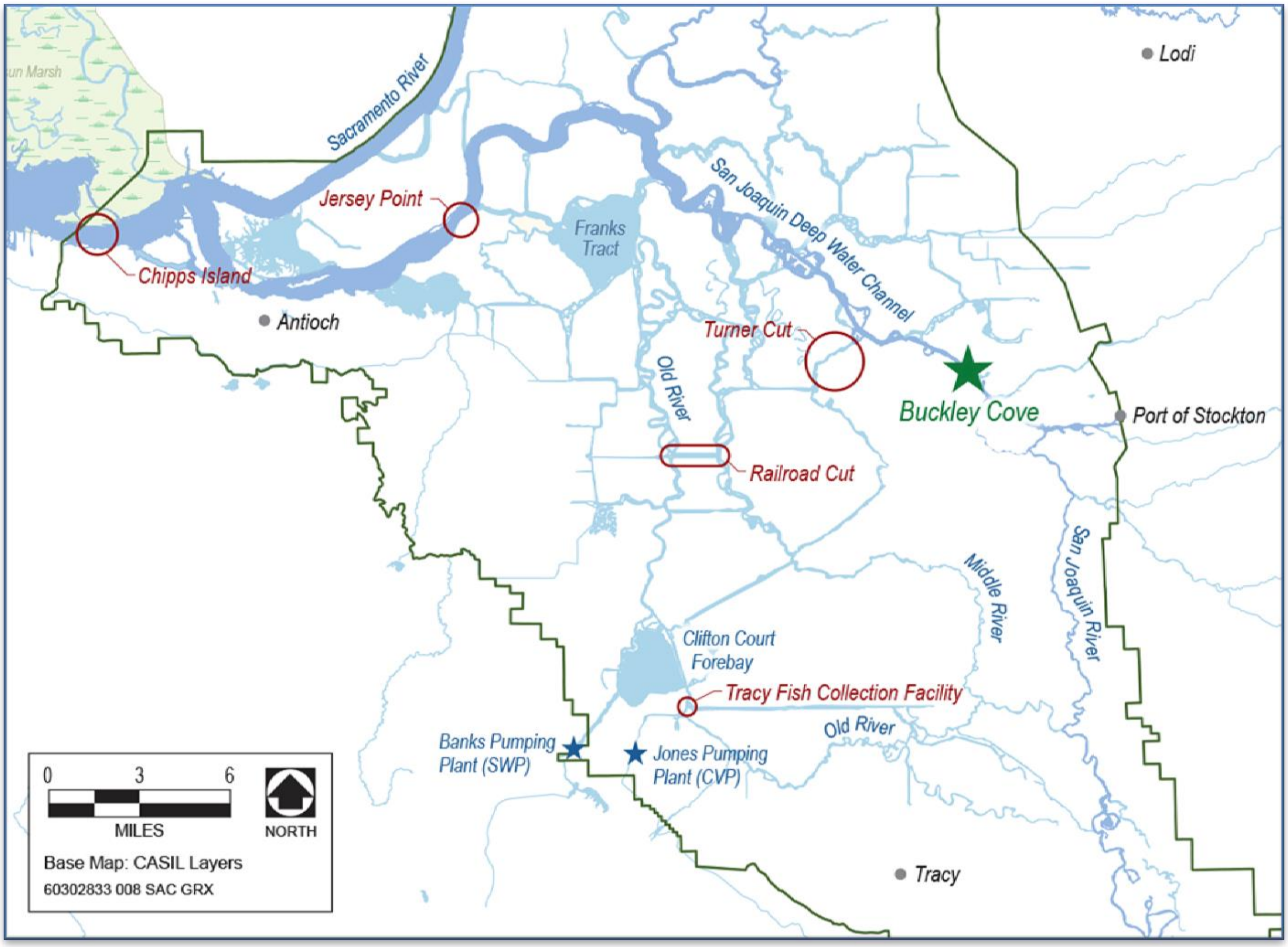


Figure 1-1 Locations of Chipps Island, Jersey Point, Railroad Cut, Turner Cut, the SWP, and the state and federal export facilities in relation to the 2012 Stipulation Study's release location near Buckley Cove (depicted by the green star).

Flow management during winter and spring has become the focus of management actions for fish protection along the OMR corridor. These management actions are calendar- and trigger-based during the period when ESA-covered salmonids are present in the Delta. If salmonid protection measures could be implemented based on fish presence farther from the export facilities, it is hypothesized that: (1) the duration of direct risks and indirect risks to salmonids associated with the export facilities may be reduced; and (2) exposure of ESA-covered salmonids to predation in south Delta channels can be reduced. The ultimate goal is to increase through-Delta survival and abundance of salmonids entering the ocean.

Under the Study Plan for the Stipulation Study (NMFS 2012), beginning in early to mid-April, when supplemental steelhead releases began, OMR flow targets shifted to a pilot “managed-risk experimental” approach. This approach implemented different OMR flow “treatment levels” for each Stipulation Study release of acoustically tagged steelhead to gather information about responses of tagged fish to different hydrodynamic conditions. The approach also included an “exposure trigger” (NMFS 2012) that, if reached or exceeded, shifted operations from the experimental OMR flow level to the less negative OMR flow level within the adaptive range (-1,250 cubic feet per second [cfs]). This trigger was intended to protect steelhead by shifting hydrodynamic conditions in a direction that may be less disruptive to outmigration routing or timing and improve survival through the Delta. The ordering of OMR flow management targets through April and May was intended to maximize the feasibility of implementing these targets while avoiding confounding OMR flow management targets with temperature.

NMFS measured the exposure trigger as the cumulative fraction of the supplemental release group that passed a pair of receiver arrays on Old River and Middle River near Railroad Cut and was designed to protect steelhead by shifting hydrodynamic conditions in a direction thought to be less disruptive to outmigration routing or timing. NMFS calculated the “Railroad Cut trigger” as 5% of the release group reaching the acoustic receiver arrays at Railroad Cut, under the assumption that 5% of fish arriving at Railroad Cut would be expected to result in a 2% loss of the release group at the fish collection facilities (NMFS 2012). We assumed that juvenile steelhead migrate fairly rapidly through the Delta and likely do not spend more than 14 days in the Delta. We found this to be true as 94% of the steelhead tags that were ever detected at Chipps Island were detected within 15 days after their release. Thus, for each Stipulation Study release, NMFS based the primary trigger on fish only from that release and not from prior releases.

The NMFS biological opinion included an RPA action that required the design and implementation of a Six-Year Acoustic Tag Study (Six-Year Study) of juvenile steelhead in the San Joaquin River. Studies of the survival and movement patterns of juvenile Chinook salmon in the Delta have also been conducted in the past as part of the Vernalis Adaptive Management Program (VAMP) and other programs (e.g., south Delta temporary barrier project, etc.). The experimental design implemented for the 2012 Stipulation Study represents an augmentation and expansion of the Six-Year Study.

In addition to providing information about the effects of OMR flows on route selection and survival in the south Delta, we also tested an alternative approach to managing water export risks to ESA-listed salmonids. The experimental approach relied on releases of “sentinel fish” and monitoring stations to detect patterns of movement of these fish within the south Delta. Sentinel fish were acoustically tagged fish assumed to represent wild fish in the system. Thus, rather than using modeling results to predict broad-scale, often subtle hydrodynamic changes hypothesized to cause indirect effects on fish survival through the Delta, the sentinel fish approach set a threshold based on the observed movement of tagged fish within the Delta. Protection measures were implemented when this threshold was exceeded.

In summary, we sought to evaluate the relationship between OMR flows and the migration and survival of juvenile salmonids, while at the same time conducting an adaptive management experiment intended to help refine decision-making for the protection of San Joaquin River steelhead.

1.3 STUDY HISTORY AND TIMELINE

The Department initiated the Stipulation Study in February 2012 and completed field operations by that summer. The preliminary results from this field study were reported in a status report issued October 15, 2012 (Cavallo et al. 2012). The Independent Review Panel (IRP) released its review of the project in the form of its Report of the *2012 Delta Science Program Independent Review Panel (IRP) on the Long-term Operations Opinions (LOO) Annual Review* (hereafter referred to as the “2012 IRP LOO Annual Review”) on December 1, 2012 (Kneib et al. 2012). Funding for additional data analysis and final report production was finalized on February 21, 2013. A

Data Analysis Plan for Phase II of the project was submitted to representatives of various federal, state, and local agencies on March 29, 2013 (Cramer Fish Sciences 2013). A meeting was held on April 19, 2013 to assess the Data Analysis Plan and our response to the reviewers' feedback. Below, we document these events, the challenges, and changes made to the document through the process that have resulted in the analysis that is presented in this report.

The analysis for the Stipulation Study was conducted in two phases.

- **Phase I.** A preliminary analysis of the data completed in October 2012 focusing on routing of steelhead tags at key Delta junctions, and an initial examination of the effect of OMR flows and local hydrodynamics on steelhead tag movement.
- **Phase II.** A thorough analysis of data completed by February 2014, including the development of a multistate statistical release-recapture model built in the User Specified Estimation Routine (USER) program (Lady et al. 2008) to estimate survival, route entrainment, transition probabilities, and detection probabilities. Multiple secondary hypotheses to examine how OMR flows affected steelhead tag behavior were also tested. These results are reported in the results section of this report (Chapter 4).

Additional details regarding the process of developing the 2012 experimental design and analysis are summarized in Table 1-1, and described below.

Table 1-1 Major events and dates conducted for this project.

Project initiated and data for report were collected	February – June 2012
Phase I Report	October 15, 2012
Phase I animation and results presented at 7th Biennial Bay-Delta Science Conference 2012 held in Sacramento, California	October 16-18, 2012
Delta Science Program Independent Review Panel Report	December 1, 2012
Work Team Meeting	December 6, 2012
Phase II Data Analysis Plan submitted to agencies	March 29, 2013
Work Team meeting	April 19, 2013
Final Data Analysis Plan	June 28, 2013
Results Work Team meeting	August 28, 2013
Draft Technical Report distributed for review	November 19, 2013
Final Department Technical Report was released	February 2014

PROJECT INITIATION AND DATA COLLECTION (FEBRUARY – JUNE, 2012)

The Department initiated the project in February of 2012. In the spring of 2012, the mark-recapture experiment was conducted to examine the survival and movement patterns of acoustically tagged juvenile steelhead emigrating through the south Delta. Three groups of juvenile steelhead were released near Buckley Cove in the lower San Joaquin River downstream of Stockton and upstream of Turner Cut (Figure 1-1). Juvenile steelhead for the study were provided by the Mokelumne River Hatchery. Releases for Group 1 began on April 15 and finished on April 16. Group 2 releases began on May 1 and finished on May 2. Group 3 releases began on May 15 and finished on May 16. The tagging and releases for Release Group 1 were complicated by severe thunderstorms. Release Groups 2 and 3 did not have any of these complications.

On average, 167 acoustically tagged steelhead were released for each of the three release groups. Data collection was completed by the end of June 2012.

PHASE I REPORT (OCTOBER 15, 2012)

The Phase I Report was completed on October 15, 2012. The following objectives were addressed in the report:

- **Objective 1:** Identify the fraction of acoustically tagged steelhead that were observed moving south at Middle and Old rivers near Railroad Cut and used as an exposure risk trigger to manage OMR flows.
- **Objective 2**: Evaluate how hydrodynamic factors influenced the route entrainment into the interior Delta from Turner Cut, Colombia Cut, and Middle River.
- **Objective 3:** Evaluate how hydrodynamic conditions and OMR flows influenced migration behavior and survival in the interior Delta.

Fine-Scale Hydrodynamic Data Difficulties

Sub-daily (15-minute) hydrodynamic influences (proportional flow movement at junctions, average flow, percent positive flow) on fine-scale fish movement were expected to be analyzed to examine how tidal influences affect juvenile steelhead migration into the interior Delta, and patterns of migration behavior and survival once fish enter the interior Delta. However, as statistical analyses were being completed, we consistently observed fish moving opposite the direction of flow movement at the Turner Cut junction (the only junction analyzed in this way). These unexpected movement patterns were observed for both steelhead and Chinook smolts, suggesting these findings likely were not a true observation of fish behavior, but rather a spurious artifact of fish timing not being in-sync with available sub-daily Delta Simulation Model II (DSM2) flow data used to inform flow conditions.

To examine if the fish and flow timing were out of sync, we compared DSM2 output near Turner Cut with observed flow data at the gauging station. For an example 24-hour period, we examined how the 15-minute flow data for the DSM2 channel 172 (Figure 1-2) immediately downstream (toward pumping facilities) of Turner Cut varied from actual observed flow data from the gauging station at Turner Cut (TRN) near Holt (via the California Data Exchange Center [CDEC]). This gauging station is operated by the USGS.

Figure 1-2 The location of DSM2 channel 172 and the gauging station at Turner Cut.

Although the daily flow magnitude was similar between datasets, the tidal cycle appeared to be off-sync by approximately 2 hours (Figure 1-3). We were unable to determine whether DSM2 Hydro or CDEC data were correct, and most locations of interest for this analysis do not host a CDEC-reported monitoring station. If the CDEC data represent the true flow conditions, then by analyzing DSM2 Hydro data at Turner Cut and other locations, we may be relating fish behavior with incorrect flow conditions. Preliminarily, we believed our findings of fish (both Chinook and steelhead smolts) moving against flow movement were likely a result of fish timing being paired with flow conditions opposite of what they may have actually experienced. Rapid changes in tidal flow conditions mean that small discrepancies in timing between predicted and actual flow patterns can lead to results directly the opposite of expectations.

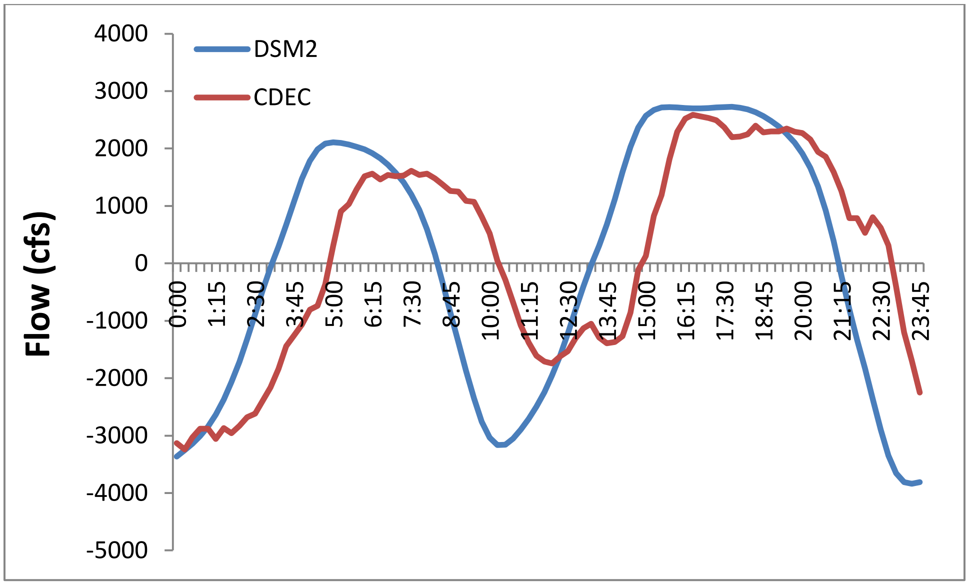


Figure 1-3 15-minute flow data over an example 24-hour period for DSM2 channel 172 and the gauging station at TRN, both indexing flow immediately downstream (toward pumping facilities) of the Turner Cut junction. Source: Cavallo et al. 2012.

This problem brought to our attention the extraordinary importance of having accurate times reported for steelhead detections. Minor discrepancies in clock settings for computers used to launch or download receiver data could lead to inaccurate time data. It is important to note that this analysis attempted to examine sub-daily fish behavior and flows in an unusually detailed way. As a consequence of these problems with how to use and reconcile DSM2 Hydro and CDEC data, findings in the Phase I Report were largely descriptive—examining broad-scale relationships between fish behavior and OMR flow conditions, or DSM2 data at a daily scale. Although this is only a single location, this further exemplified the difficulty of examining fine-scale flow and steelhead tag relationships using the existing hydrodynamic data available. Because of the strong tidal influence in the Delta, flow measurements and steelhead tag observations must be paired perfectly together to know exactly what the flow conditions a steelhead tag was experiencing when making a routing "decision." Therefore, all Phase II analyses used average 2-hour or daily periods to estimate the hydrodynamic conditions.

PHASE I ANIMATION AND RESULTS PRESENTED AT 7TH BIENNIAL BAY-DELTA SCIENCE CONFERENCE 2012 HELD IN SACRAMENTO, CALIFORNIA – OCTOBER 16–18, 2012

We presented an animation of the particle and steelhead data at the 7th Biennial Bay-Delta Science Conference 2012 held at the Sacramento Convention Center in Sacramento, California. The animation is located online and can be viewed the following website address: http://www.fishsciences.net/projects/media/Stip_Study_Animation.mp4.

We compared the relative movement patterns of simulated particles with steelhead tags to evaluate the efficacy of using simulated particles (DSM2 Particle Tracking Model [PTM]) to mimic steelhead tag behavior. We generated an animation of steelhead tags and simulated particles. The animation is based on raw data, and detection probabilities were not considered. Therefore, movement patterns of steelhead tags depict actual tag movement and the ability of each receiver array to detect each tag. However, it is important to note that detection probability was only found to vary across release groups for receiver 6. Therefore, differences in broad movement patterns between release groups should generally reflect actual differences in tag movement. Given the data observed, the following figures display screen shots from the animation, depicting days 3 and 7 after release for Release Group 1 (Figure 1-4 and Figure 1-5), Release Group 2 (Figure 1-6 and Figure 1-7), and Release Group 3 (Figure 1-8 and Figure 1-9).

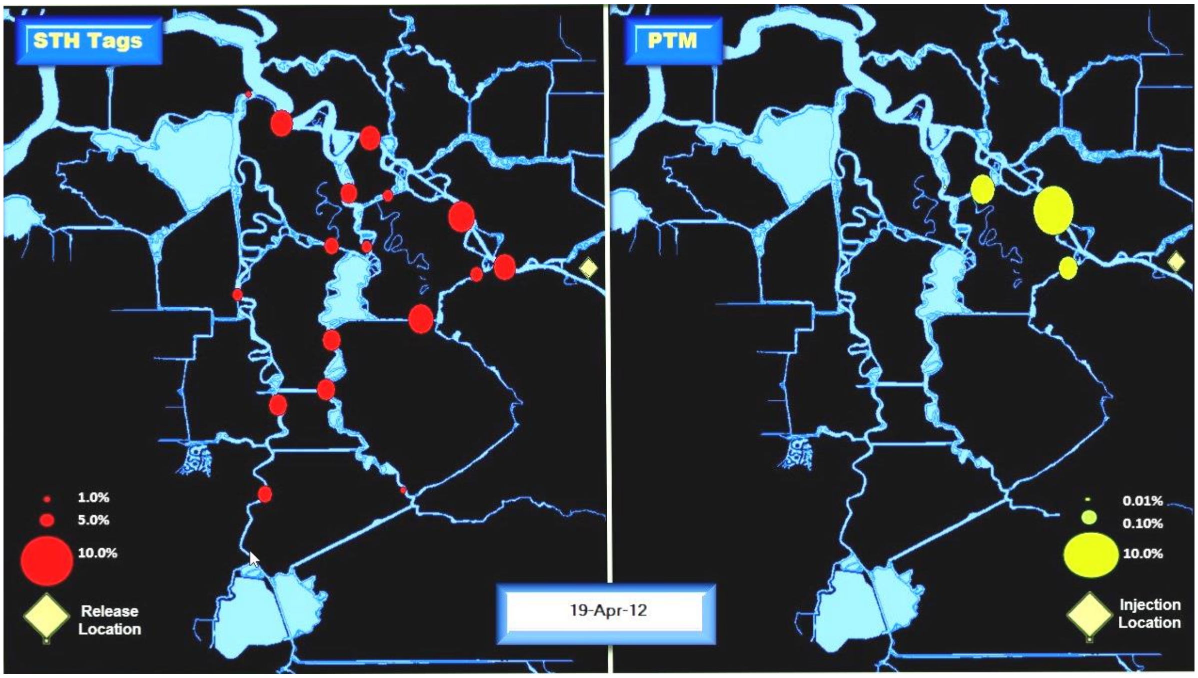


Figure 1-4 **The proportion of steelhead tags (STH tags) and simulated particles (PTM) located at each array for Release Group 1 on the third day after the fish releases were completed (April 19, 2012).**

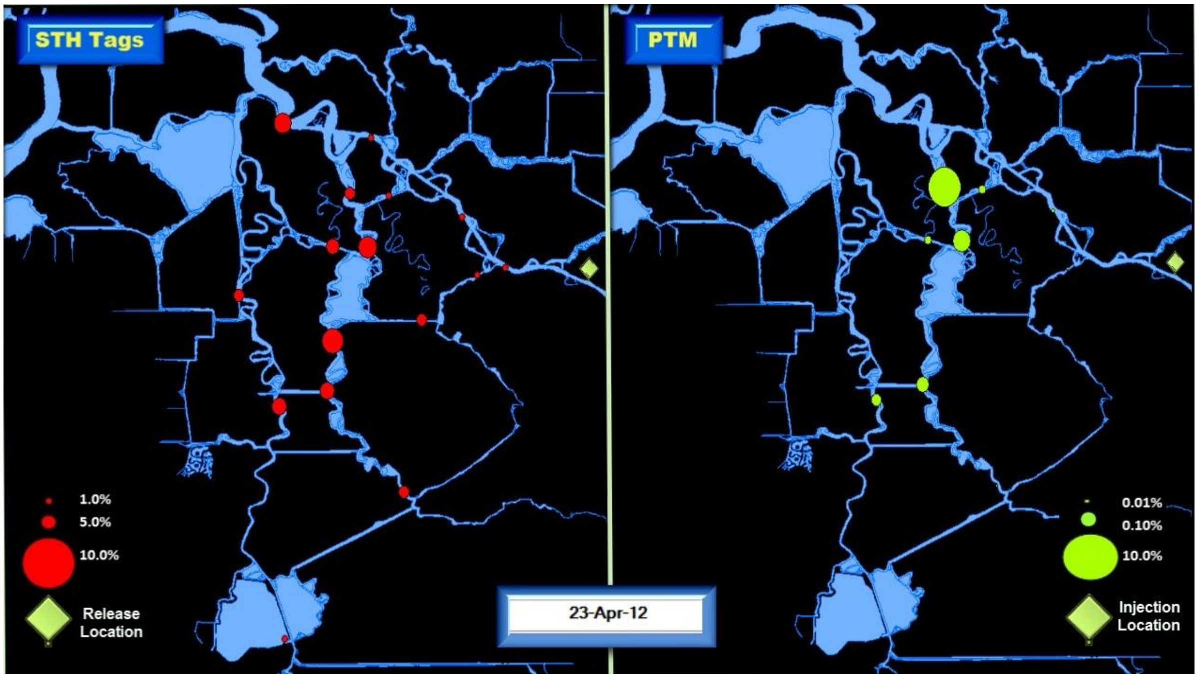


Figure 1-5 The proportion of steelhead tags (STH tags) and simulated particles (PTM) located at each array for Release Group 1 on the seventh day after the fish releases were completed (April 23, 2012).

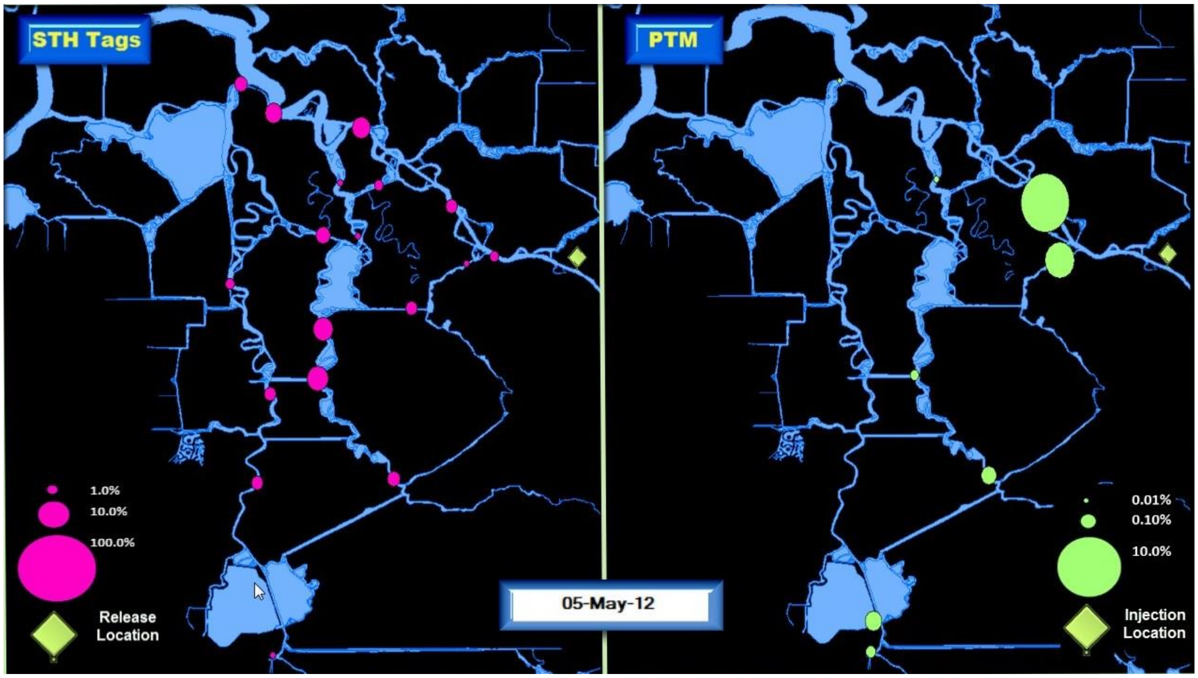


Figure 1-6 The proportion of steelhead tags (STH tags) and simulated particles (PTM) located at each array for Release Group 2 on the third day after the fish releases were completed (May 5, 2012).

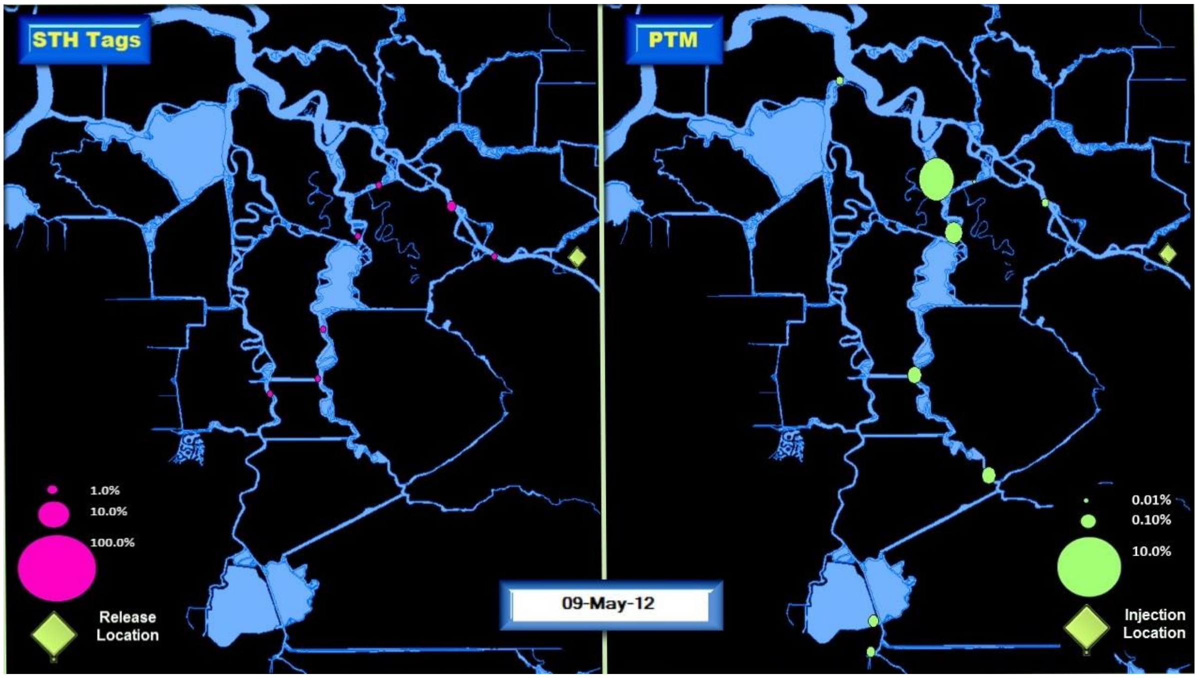


Figure 1-7 The proportion of steelhead tags (STH tags) and simulated particles (PTM) located at each array for Release Group 2 on the seventh day after the fish releases were completed (May 9, 2012).

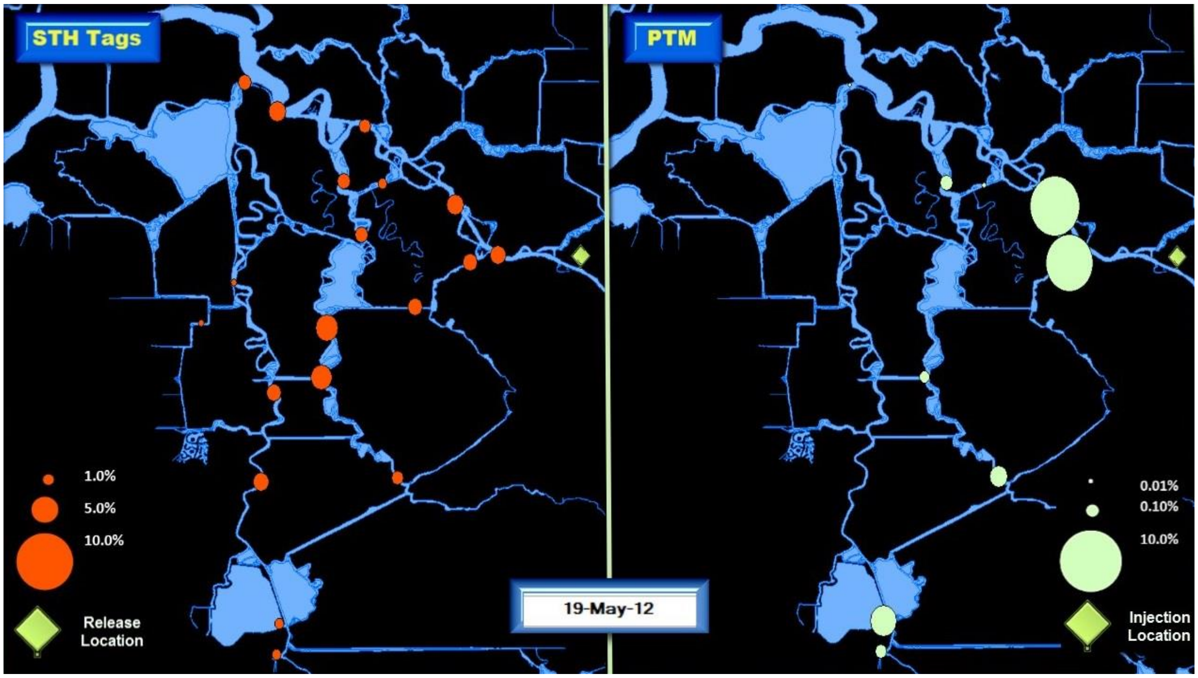


Figure 1-8 The proportion of steelhead tags (STH tags) and simulated particles (PTM) located at each array for Release Group 3 on the third day after the fish releases were completed (May 19, 2012).

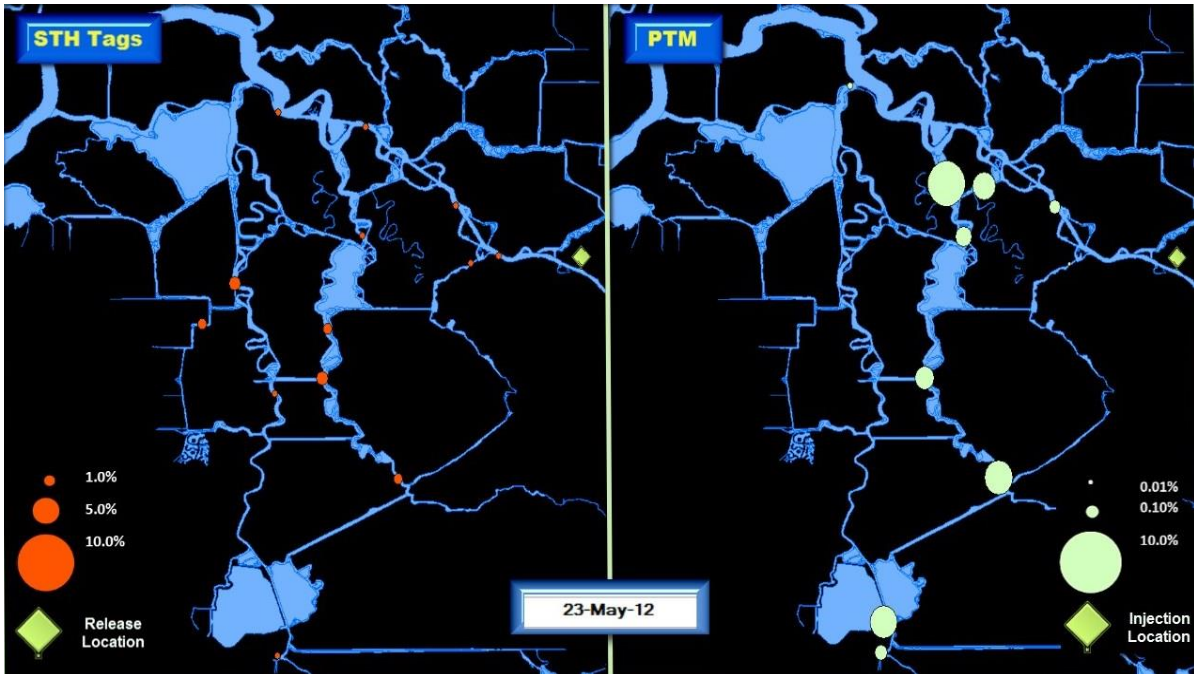


Figure 1-9 **The proportion of steelhead tags (STH tags) and simulated particles (PTM) located at each array for Release Group 3 on the seventh day after the fish releases were completed (May 23, 2012).**

DELTA SCIENCE PROGRAM INDEPENDENT REVIEW PANEL REPORT (DECEMBER 1, 2012)

An IRP was assembled by the Delta Science Program to inform NMFS and the USFWS as to the efficacy of the water operations and regulatory actions prescribed by their respective LOO RPAs as applied from October 1, 2011 through September, 30 2012 (Water Year 2012). The 2012 annual review focused in part on the implementation of NMFS's RPA for the Spring 2012 Delta Operations Joint Stipulation for water operations and fisheries that was required to be executed in water year 2012 in lieu of the NMFS RPA Action IV.2.1. The IRP released the 2012 IRP LOO Annual Review on December 1, 2012, which detailed their review of preliminary analysis of Stipulation Study acoustic data detailed in the Phase I Report. Their assessment of this report can be downloaded from: http://deltacouncil.ca.gov/sites/default/files/documents/files/Report_2012_DSPIRP_LOOAR_120112_final.pdf.

The IRP presented three major criticisms of the Phase I analysis, summarized as follows:

- Tidal Influences: The effect of tidal hydrodynamics on the movement and survival of smolts though the Delta was not addressed in the Phase I analysis. The current paradigm for characterizing movement of smolts through the Delta reaches relies on mean flow to characterize the movement and routing of fish. The steelhead tagging studies in 2012 and earlier years clearly indicated that this characterization is inadequate. Therefore, the IRP suggested that the travel, routing, and survival of fish through the system needed to account for migrant behavior and the behaviors of the predators in response to the strong tidal influences in the Delta (Kneib et al. 2012).

- Inadequate Statistical Analysis: The IRP stated that many of the Phase I study's initial conclusions were not adequately supported by the analyses because they failed to make use of statistical testing or confidence intervals, and they suggested that the analyses be redone with greater statistical rigor, where possible.

- Re-coding Release Groups: The IRP suggested re-coding the release groups to test for evidence of an OMR flow effect on fish behavior within the range of flow levels examined using the available data. They suggested recoding Release Groups 1 and 2 as "intermediate" OMR flow, and Group 3 as "high" OMR flow. Groups 1 and 2 can be pooled as "intermediate" flow treatment level and compared to Group 3 as "high" flow treatment level. In this report, we refer to data from Groups 1 and 2 as less negative OMR flows and Group 3 as more negative OMR flows.

The IRP suggestions provided us with a direction moving forward with the Phase II analysis. As suggested by the IRP, we incorporated a hypothesis that examined the movement of steelhead tags in relation to tidal hydrodynamics in a small reach of the interior Delta. However, the large-scale mechanistic analysis suggested by the IRP was not possible with the data available, and would require fine-scale hydrodynamic data collected simultaneously with fish movement data, which are unavailable with the current dataset. Second, as many analyses as possible in Phase II were tested statistically. Likewise, a statistically rigorous multistate release-recapture model was applied to examine fish routing and survival. Lastly, release groups were re-coded as suggested by the IRP, with Groups 1 and 2 as less negative OMR flow, and Group 3 as more negative OMR flows, to better examine the effect of OMR flows on steelhead tag behavior.

WORK TEAM MEETING (DECEMBER 6, 2012)

A technical Work Team comprised of participants from the Department, Reclamation, USGS, NMFS, USFWS, and the consultant team working on the project was convened to help address issues and discuss data analysis topics as they arose. The Work Team met on December 6, 2012, to discuss the initial draft of the data analysis plan for Phase II analyses. The discussion primarily focused on three major topics:

- Hydrodynamics: As described earlier, the difficulties with trying to examine fine-scale (sub-daily) movements of steelhead tags in relation to flow were discussed. The general consensus was that only daily hydrodynamic data would be paired with tag data.

- Inclusion of Six-Year Study Tags: A discussion of whether or not to include Six-Year Study tags in the Phase II analyses was conducted. The general agreement was that the analysis of Stipulation Study tags was the primary goal of the Phase II analysis, and therefore the Six-Year Study tags would be left out of Phase II analyses, except if additional time and resources were available to examine them at the end.

- Particle Tracking Comparisons: In the Phase I analysis, comparisons between the movement of steelhead tags and simulated particles were conducted to examine the efficacy of using simulated particles to mimic fish behavior. The Work Team discussed the need for additional analyses in Phase II and agreed that one additional analysis examining the end location of tags and particles would be beneficial.

PHASE II DATA ANALYSIS PLAN SUBMITTED TO AGENCIES (MARCH 29, 2013)

Funding for Phase II of the project was finalized on February 21, 2013. Many of the action items from the December 6 meeting were completed and incorporated into a draft of the Data Analysis Plan completed on February 11, 2013. A Data Analysis Plan for Phase II was submitted to representatives of various federal, state, and local agencies on March 29, 2013. We received feedback and responded to the reviews by email on April 17, 2013.

DATA ANALYSIS PLAN PRESENTED TO THE WORK TEAM MEETING (APRIL 19, 2013)

A Work Team meeting was held on April 19, 2013, to discuss the Phase II Data Analysis Plan and the response to the reviews. Suggested revisions and comments were sent prior to the meeting, discussed during the meeting, and followed-up after the meeting.

FINAL DATA ANALYSIS PLAN (JUNE 28, 2013)

Following receipt of comments from the Work Team on the draft Data Analysis Plan for Phase II, a final plan was created and submitted to the Department for final review and approval. This document laid the groundwork for the analysis contained in this report.

PRELIMINARY RESULTS PRESENTED TO THE WORK TEAM MEETING (AUGUST 28, 2013)

The preliminary results of the Phase II analyses were presented to the Work Team during a meeting on August 28, 2013. Some of the major discussion points during the meeting were the following:

- New Qualitative Analyses: New qualitative analyses were presented for the first time, including a web-based data viewer tool of Stipulation Study steelhead tag data, and new descriptive figures of the final fate of steelhead tags.

- Release-specific Model Did Not Converge: The mark-recapture models that only used data from an individual release group did not converge for all release groups; therefore, we ran the model on all release group steelhead tag data as a single model. When the model was run using all the data, it converged. Therefore, the effect of release group on steelhead tag behavior and survival was examined exclusively in the Objective 2 hypotheses.

- Array 6 versus 7: The detection probabilities experienced across release groups at these dual receiver arrays were examined. The results showed that detection probabilities at array 6 varied greatly across release groups. Because receiver 7 showed consistently high detection probabilities across all release groups, the mark-recapture model was run with receiver 7 instead of receiver 6. Likewise, array 7 was used in all Objective 2 hypotheses where Turner Cut was examined. For more detail, see Section 4.2.1.

- Study History Table: The Work Team asked that a table be created detailing the changes in objectives and hypotheses since the first incarnation of the Data Analysis Plan (see Appendix A for the concordance table).

- Reorganization of Objectives and Hypotheses: A re-organization of study objectives was agreed upon for the final report that grouped all hypotheses into different spatial categories, including system, route, and junction.

This entire study process described above along with the collaboration with the interested parties led to the development of the study objectives and this final report. A detailed history of the Phase II analyses, including the evolution of study objectives and hypotheses, is presented in the concordance table in Appendix A.

DRAFT OF FINAL REPORT DISTRIBUTED TO THE WORK TEAM (NOVEMBER 18, 2013)

The preliminary results of the Phase II analyses, a draft of this report, were distributed to the Work Team by the Department.

FINAL REPORT PUBLISHED (FEBRUARY 7, 2014)

The final Technical Report was released following the review by the Work Team.

1.4 STUDY ANALYSES

The analysis was spatially divided into three sections: system-wide, route, and junction-level. The first set of analyses focused on large-scale movement patterns and whether a particle simulation model could predict the system-wide movement patterns of steelhead tags. In the second section, we examined how steelhead tags moved through the system using different defined routes. We examined if their transition, detection, survival, route entrainment, and travel times were affected by different OMR flow conditions. In the last section, we examined how fish moved through key Delta junctions (Turner Cut, Columbia Cut, Middle River, and Railroad Cut). The following describes the areas of discussion and hypothesis-testing presented in the results section (Chapter 4). Areas of discussion are those where the data are discussed qualitatively, compared to the hypothesis where statistical tests can be applied.

4.1 System: Examine large-scale movement patterns of steelhead tags.

- Discussion 4.1.1: Relative steelhead tag detection at arrays
- Discussion 4.1.2: Last detection at arrays
- Discussion 4.1.3: Residence time at arrays
- Discussion 4.1.4: Final fate at arrays
- Discussion 4.1.5: Web-based detection history
- **Hypothesis 4.1.6**: The distance traveled by steelhead tags was not significantly different than the distance traveled by the passive particles.
- **Hypothesis 4.1.7:** Steelhead tags did not move using selective tidal-stream transport (STST).
- **Hypothesis 4.1.8:** The movement of steelhead tags in the San Joaquin River and interior Delta was not related to day/night.

4.2 Route: Examine how steelhead tags move through the system using different defined routes.

- **Hypothesis 4.2.1**: Route-specific transition probabilities of steelhead tags were not significantly related to the route taken and/or release group.
- **Hypothesis 4.2.2:** The estimated route-specific survival for the Turner Cut route was not significantly different from the Mainstem route.
- **Hypothesis 4.2.3**: The travel times of steelhead tags were not significantly different between routes or release groups.

4.3 Junction: Examine how steelhead tags move through junctions.

- **Hypothesis 4.3.1:** The probability of steelhead tags entering the interior Delta at Turner Cut, Columbia Cut, and Middle River was not related to OMR flows.
- **Hypothesis 4.3.2:** Steelhead tag arrival at each facility was not related to the proportion of total export flow entering SWP.
- **Hypothesis 4.3.3:** The movement patterns of steelhead tags after passing through Railroad Cut were not affected by OMR flows.

2 EXPERIMENTAL DESIGN AND FIELD METHODS

CHAPTER SUMMARY:

In the spring of 2012, we initiated a mark-recapture experiment to examine the survival and movement patterns of acoustically tagged juvenile steelhead emigrating through the south Delta. We released three groups of juvenile steelhead near Buckley Cove in the lower San Joaquin River downstream of Stockton, and upstream of Turner Cut (Figure 1-1). We began releases for Group 1 on April 15 and finished on April 16. We began Group 2 releases on May 1 and finished on May 2. We began Group 3 releases on May 15 and finished on May 16. All releases began at approximately 3:00 pm and ended within 24 hours. We released a minimum of 166 acoustically tagged steelhead for each of the three release groups. We obtained the juvenile steelhead from the Mokelumne River Fish Hatchery, and those steelhead were used in the 2012 Stipulation Study as surrogates for wild fish. We tagged the hatchery-produced steelhead with acoustic coded transmitters (VEMCO, model V6-4X) at the hatchery following the 2012 Stipulation Study Tagging Standard Operating Procedure (SOP). This SOP was identical to the 2012 Six-Year Study SOP. Tag burden was very low and battery life of the tags far exceeded the study period.

The study plan required the measurement of the fraction of acoustically tagged steelhead that reach and are observed to be moving southward near Railroad Cut toward the export facilities. Regulatory agencies used this fraction as an exposure risk trigger to manage OMR flows. During the study, near-real-time detections of Stipulation Study fish resulted in changes to OMR flows during each experimental period. Under the Stipulation Study Plan, beginning in early to mid-April (coincident with experimental steelhead releases), OMR flow targets shifted to a pilot “managed-risk experimental” approach. The experimental design was intended to gather information about responses of tagged fish to different hydrodynamic conditions. Different OMR flow “treatment levels” were implemented for each release of acoustically tagged steelhead. This approach included an “exposure trigger” that, if reached or exceeded, shifted operations from the experimental OMR flow level to the least negative OMR flow level within the adaptive range (-1,250 cfs). This action was intended to protect steelhead by shifting hydrodynamic conditions in a direction thought to be less disruptive to outmigration routing or timing. The exposure trigger was measured as the cumulative fraction of the supplemental release group that passed a pair of receiver arrays on Old River and Middle River near Railroad Cut. The trigger was calculated as 5% of the release group reaching the acoustic receiver arrays at Railroad Cut, under the assumption that 5% of fish arriving at Railroad Cut would be expected to result in a 2% loss of the release group at the fish collection facilities (NMFS 2012).

The original experimental design called for each 2-week experimental period to represent one of three OMR flow targets (-1,250, -3,500, and -5,000 cfs). Real-time evaluation of tag detections at Railroad Cut for each group resulted in exceedance of the trigger for each release group, which in turn altered experimental OMR flow levels and resulted in variable OMR flows during the study. Average observed OMR flows during the first 7 days following release were -2,446, -2,933, and -5,038 cfs for Release Groups 1, 2, and 3, respectively (Figure 2-1).

One of the major goals of this report was to determine if behavioral differences exist between any of these three release groups in relation to OMR flow. Also, based on a recommendation in the 2012 IRP LOO Annual Review (Kneib et al. 2012), the analysis pooled the data from Release Groups 1 and 2, which were considered a less negative OMR flow group and were compared to the data from the more negative flow treatment level data from the third release group.

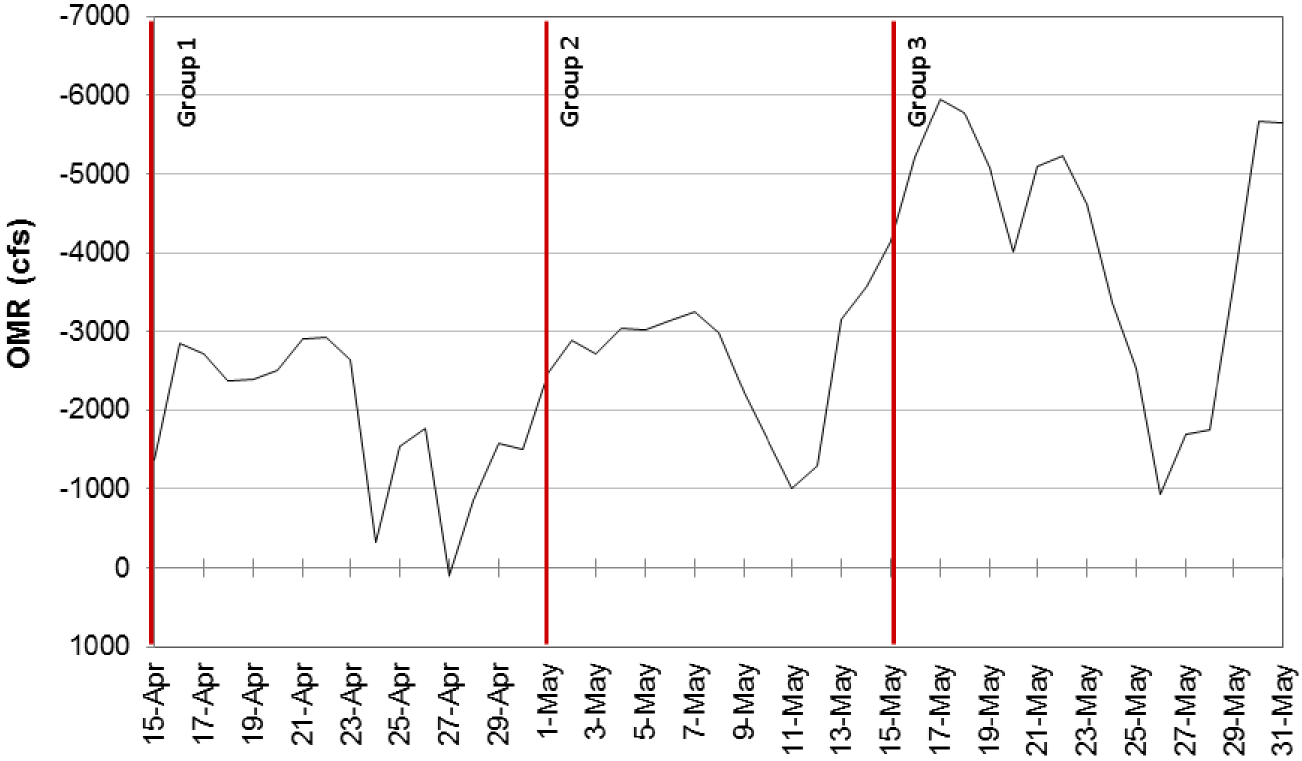


Figure 2-1 **Daily OMR flow conditions and release dates for acoustically tagged steelhead smolts from the 2012 Stipulation Study.**

2.1 HYDRODYNAMIC SETTING

In the spring of 2012, a mark-recapture experiment was performed to examine the survival and movement patterns of acoustically tagged juvenile steelhead emigrating through the south Delta. We released three groups of juvenile steelhead near Buckley Cove in the lower San Joaquin River downstream of Stockton, and upstream of Turner Cut (Figure 1-1). Releases for Group 1 began on April 15 and finished on April 16. Group 2 releases began on May 1 and finished on May 2. Group 3 releases began on May 15 and finished on May 16. The original experimental design called for each 2-week experimental period to represent one of three OMR flow targets (-1,250, -3,500, and -5,000 cfs). Real-time evaluation of steelhead tag detections at Railroad Cut for each group resulted in exceedance of the trigger for each release group, which in turn altered experimental OMR flow levels and resulted in variable OMR flows during the study. Average observed OMR flows during the first 7 days following release were -2,446, -2,933, and -5,038 cfs for Release Groups 1, 2, and 3, respectively (Figure 2-1). The triggered less negative OMR flow levels (-1,250 cfs) were observed to be achieved on April 24, May 11, and May 26 for Release Groups 1 through 3, respectively (Figure 2-1). Figure 2-2 shows the daily export rates entering Clifton Court Forebay and CVP, these two values combined, and flows of the San Joaquin River at Vernalis during the three release periods of the study.

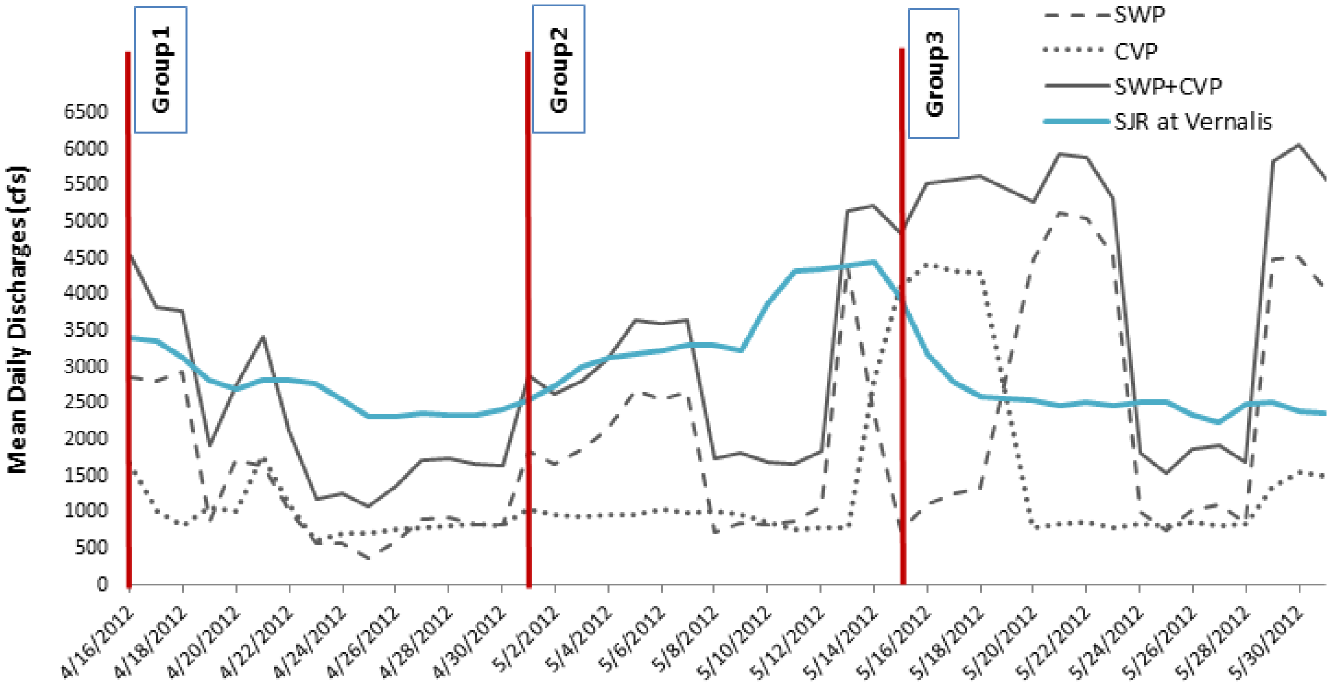


Figure 2-2 Mean daily export flows at the SWP and CVP, combined export flows, and flow discharge of San Joaquin River (SJR) at Vernalis in relation to steelhead release groups.

2.2 ACOUSTIC ARRAYS, RECEIVER DEPLOYMENT, AND REPORTING

2.2.1 ACOUSTIC RECEIVER ARRAYS

VEMCO VR2W-180 kilohertz (kHz) receivers were used to continuously monitor for the presence of acoustically tagged juvenile steelhead. A total of 33 receivers were deployed at 15 different sites within the south and central regions of the Delta (red squares in Figure 2-3). We placed at least one receiver on each side of the riverbank and two to four receivers at each site to attempt to provide full coverage of the channel cross-section. The VR2W-180 kHz receivers are omni-directional passive acoustic listening stations that record and store the presence of multiple acoustic transmitters. Each fixed-position hydrophone provided detailed date and time information regarding the presence of tagged steelhead at each specific site. We complemented these acoustic receiver arrays with nine acoustic receiver arrays from the Six-Year Study (blue squares in Figure 2-3) for a total of 24 arrays used for analysis (Table 2-1).

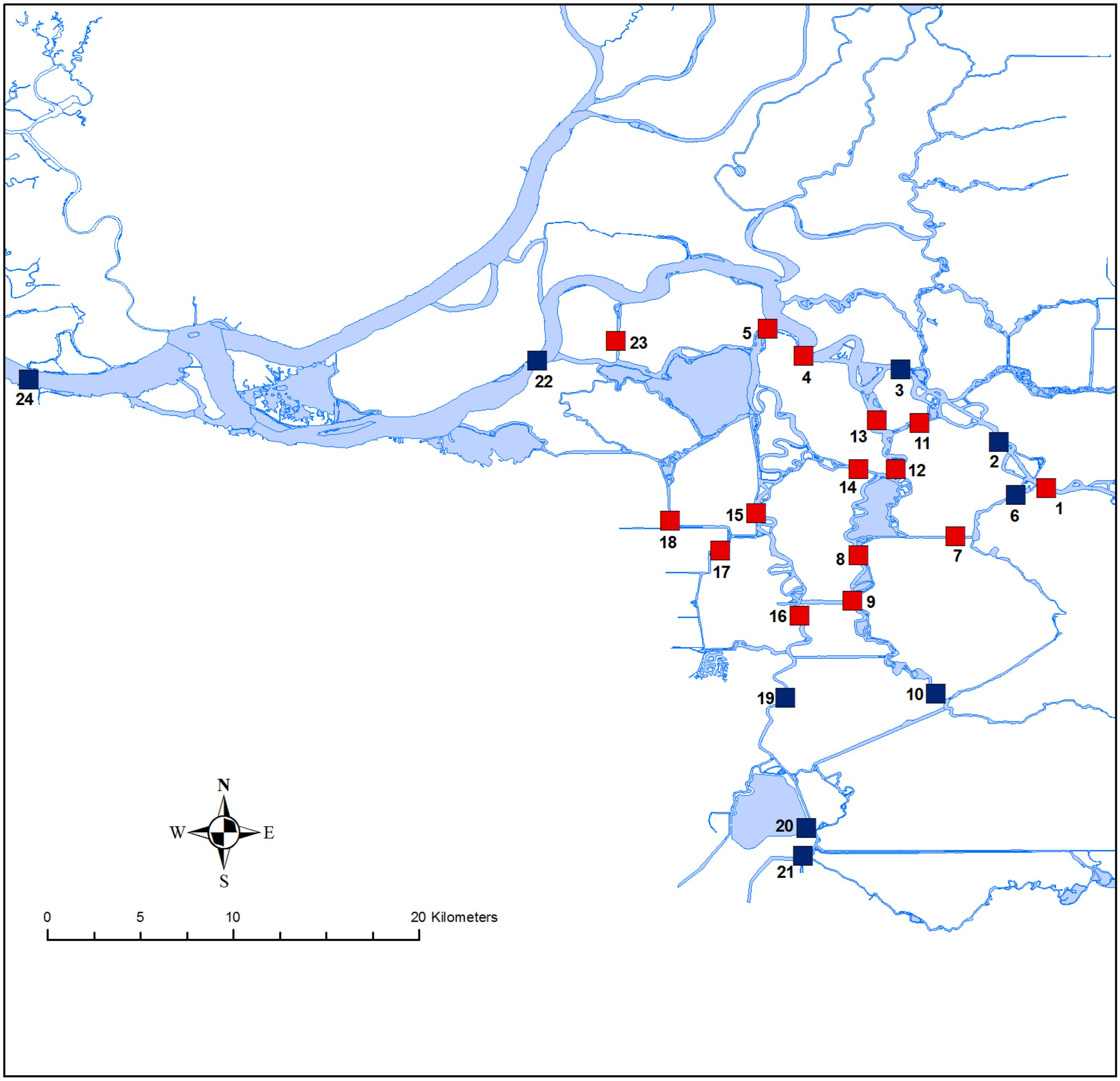


Figure 2-3 **The 24 acoustic receiver array sites in the south Sacramento-San Joaquin Delta.** The red squares are sites where arrays were deployed for the Stipulation Study. The blue squares are sites where arrays were deployed for the 2012 Six-Year Study.

Table 2-1 The array number, its latitude (decimal degrees), longitude (decimal degrees), what study the arrays were deployed for (Stipulation Study denoted as "Stip" or for the Six-Year Study denoted as "6yr"), and a description of the where the array was located.

Array	Study	Latitude	Longitude	Site Description
1	Stip	37.9949	-121.4404	An array along the San Joaquin River upstream of Turner Cut
2	6yr	38.0175	-121.4634	An array along the San Joaquin River downstream of Turner Cut
3	6yr	38.0524	-121.5111	An array along the San Joaquin River at the north point of Medford Island
4	Stip	38.0589	-121.5580	An array along the San Joaquin River at the southwest tip of Venice Island
5	Stip	38.0721	-121.5754	An array along the San Joaquin River at the southeastern tip of Webb Tract and northwest tip of Mandeville Island
6	6yr	37.9917	-121.4554	An array in Turner Cut
7	Stip	37.9719	-121.4846	An array in Empire Cut, downstream of Turner Cut
8	Stip	37.9626	-121.5316	An array in the northwest region of Jones Tract and just south of Mildred Island
9	Stip	37.9407	-121.5344	An array at the east end of Railroad Cut
10	6yr	37.8958	-121.4939	An array in Middle River just north of its intersection with Trapper Slough and Highway 4
11	Stip	38.0267	-121.5020	An array in Columbia Cut, southeast of Medford Island
12	Stip	38.0041	-121.5132	An array at the southeast tip of Mandeville Island
13	Stip	38.0279	-121.5227	An array in Middle River at the southwest tip of Medford Island
14	Stip	38.0043	-121.5315	An array at the northeast tip of Bacon Island
15	Stip	37.9828	-121.5810	An array at the southeast part of Holland Tract
16	Stip	37.9335	-121.5598	An array at the west end of Railroad Cut and northwest of Woodward Island
17	Stip	37.9647	-121.5984	An array northwest of Palm Tract
18	Stip	37.9794	-121.6225	An array southeast of Hotchkiss Tract and southwest of Holland Tract
19	6yr	37.8938	-121.5667	An array in Old River just west of Victoria Island and north of Highway 4
20	6yr	37.8306	-121.5566	An array with receivers located upstream and downstream of the radial gates of Clifton Court Forebay
21	6yr	37.8171	-121.5583	An array with receivers upstream and downstream of the trash racks as well as an array in the holding tank
22	6yr	38.0567	-121.6869	An array along the San Joaquin River at Jersey Point
23	Stip	38.0661	-121.6487	An array located east of Bradford Island and west of Webb Tract
24	6yr	38.0476	-121.9330	An array located near Chipps Island

2.2.2 RECEIVER SET UP AND DEPLOYMENT

When deploying the Stipulation Study receivers, we bolted each receiver using metal U-bolts to 4.5–7.6 meter (m) of 0.6-centimeter (cm) diameter stainless steel cable. We attached one end of the cable to a 13.6- to 27.2-kg anchor weight. We then positioned the receiver 1.8 m above the channel bottom using a buoy that was cable-tied to the stainless steel cable. This allowed the receiver to stay in an upright position within the water column at a fixed depth. We attached the other end of the cable to a permanent fixture (i.e., tree, buoy, pier piling, etc.) on the riverbank at each site (Figure 2-4). Because one cable end was permanently attached to the riverbank, retrieval of each receiver for inspection and data download was straightforward. Coordinates for each receiver were recorded using a Global Positioning System (GPS) device to allow for easy relocation.

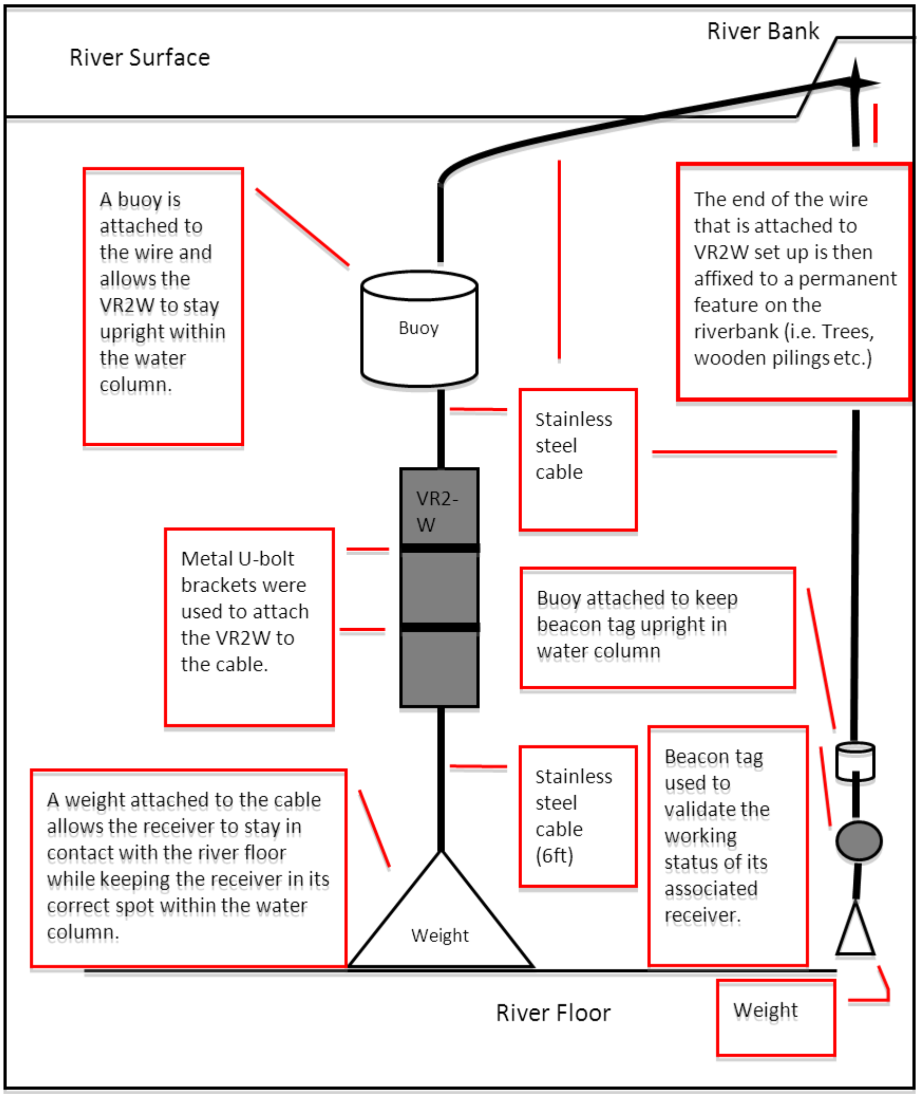


Figure 2-4 **Schematic of typical receiver deployment.**

We deployed a beacon tag or “sync” tag adjacent to each receiver to monitor and document the correct operation. The beacon tag was attached to a separate stainless steel cable connected to the receiver’s cable at each site (Figure 2-4). We attached the beacon tag to the anchor system with a buoy to keep the beacon tag about 0.6 m from the river bottom. Each beacon tag was the same model of transmitter that was implanted into the juvenile steelhead. VEMCO programmed these tags to transmit the same signal as the implanted tags but over a longer time interval. Each receiver recorded the exact beacon tag identification (ID) number, date, and time it was recorded. During data analysis, we used beacon tag detections to validate that each individual receiver was functioning properly. Proper function of the receiver was documented when there were 102 detections and corresponding data records for the beacon tag within a 24-hour period.

2.2.3 RECEIVER DATA DOWNLOAD PROCEDURE

We generated a download schedule to create a manageable, daily workload and to prioritize sites by importance and proximity to the south Delta SWP/CVP export facilities. Sites were either downloaded daily or weekly. The sites most important for management discussions were the Railroad Cut sites near OMR (array sites 9 and 16 as seen in Figure 2-5). Data from these sites were downloaded, analyzed, summarized, and distributed daily. This provided the near-real-time monitoring data necessary for the 2012 experimental design. Six-Year Study arrays were checked less frequently. The weekly downloading schedule was as follows (Figure 2-5):

- Tuesdays: arrays 4, 5, 17, 18, and 23.
- Wednesdays: arrays 1, 8, and 14.
- Thursdays: arrays 7, 11, 12, 13, and 15.

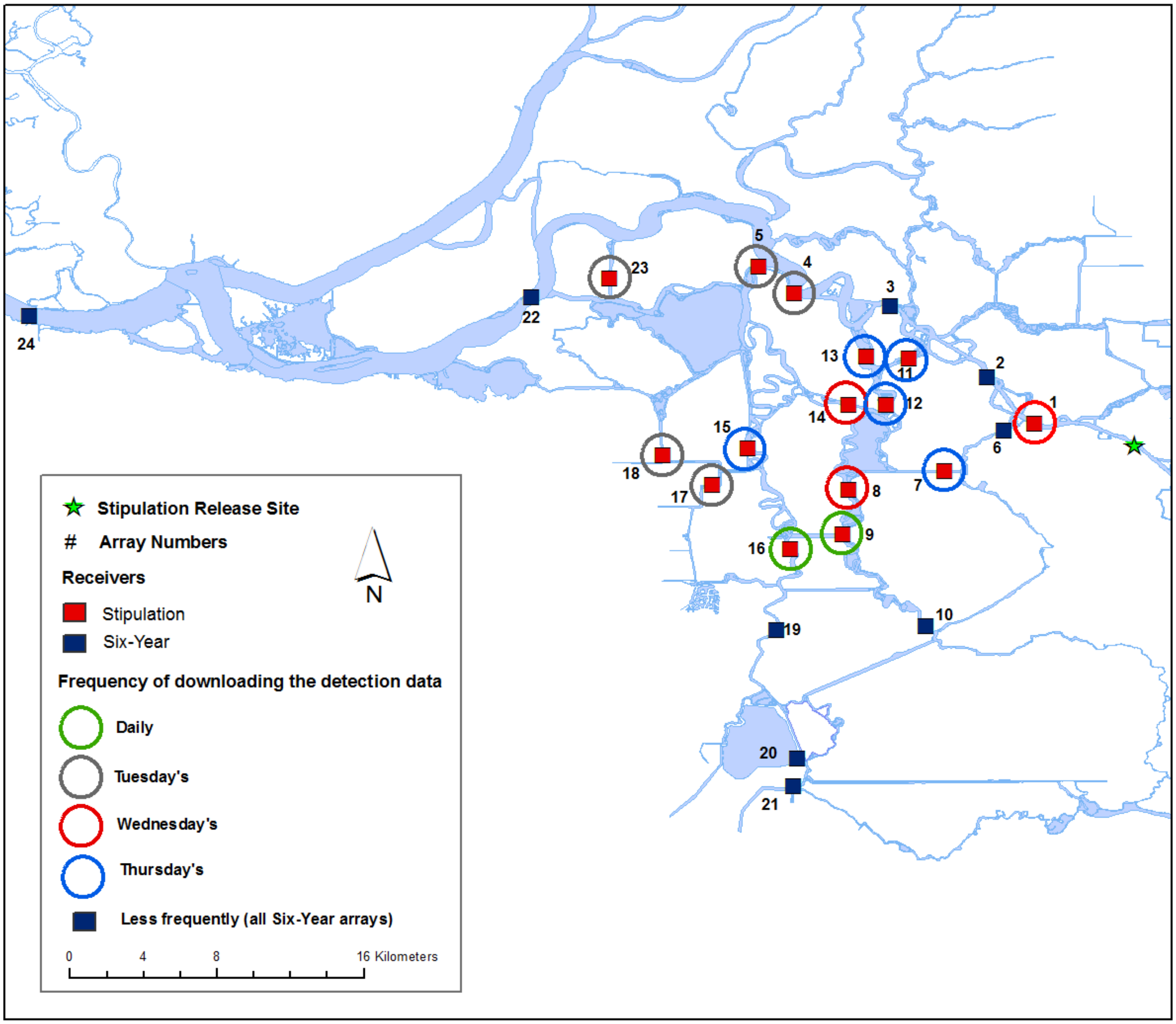


Figure 2-5 The 24 arrays color-coded by the frequency that the data were downloaded.

To retrieve the transmitter detection data from each receiver, a team of two staff used a boat to access each receiver. Using GPS coordinates, we retrieved the desired VR2W receivers from each site for that day. We inserted a Bluetooth key in the VR2W to initiate the download and a laptop aboard the boat equipped with VEMCO User Environment (VUE) software created a wireless interface with the receiver. Once we synchronized the receiver and software, we wirelessly downloaded the data from the Bluetooth enabled receiver. After each download, we erased the receiver memory of the prior days' data and immediately reset to start new detection recording. After the Bluetooth-interface with the VUE software was connected to a recorder, proper internal equipment checks were also done to ensure the receiver was actively recording and ready to be placed back into the water column. This procedure was followed for each receiver at each site according to the download schedule and helped to avoid equipment malfunctions that could occur and negatively affect the receiver performance.

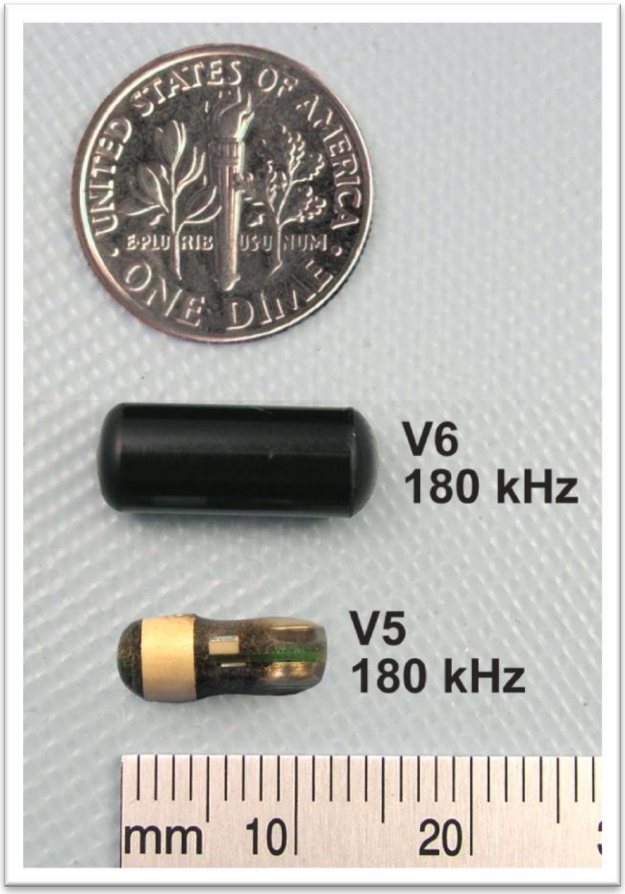
2.3 TAGGING METHODS, EVALUATION, RELEASE, TAG LIFE, AND BURDEN

2.3.1 TAGGING METHODS

We obtained juvenile steelhead from the Mokelumne River Fish Hatchery. We tagged the hatchery-produced steelhead with acoustic coded transmitters (VEMCO, model V6-4X) at the hatchery following the 2012 Stipulation Study Tagging SOP. This SOP was identical to the 2012 Six-Year Study SOP. The tags used in the Stipulation Study were compatible with the tags and receivers used with the 2012 Six-Year Study. Each V6-4X acoustic coded transmitters is 6 millimeters (mm) in diameter and 16.5 mm long (Figure 2-6).

Surgical implantation of the acoustic tags took place during three tagging events according to the detailed procedure in the tagging SOP, which is summarized here. To reduce the stress associated with chasing fish with a net, we netted juvenile steelhead from the raceway and placed them into perforated garbage cans within the raceway. We individually netted steelhead from the garbage cans and placed them into 18.9 liter (L) buckets containing 70 milligram (mg)/L of tricane methanesolfonate (MS-222). We left the juvenile steelhead in the bucket for 1–5 minutes until anesthetized. We removed the anesthetized fish from the bucket and recorded their length (mm) and weight (grams). Literature suggests that fish should not be tagged with transmitters that weigh more than 2% of the fish's body weight (e.g., Kneib et al. 2012). Because transmitters weighed 1 gram, we did not tag steelhead weighing less than 50 grams to maintain a maximum 2% tag to body weight ratio as per the literature recommendations. This was done even though the SOP would have allowed a 5% tag to body weight ratio (equaling a 20 gram fish).

We then checked each steelhead for any abnormalities. Abnormal fish were those that suffered from extremely eroded fins, abnormal body shape, or other structural deformities that could impair normal behavior. We placed abnormal fish in a reject bucket and did not tag them.



Source: VEMCO

Figure 2-6 **Examples of VEMCO acoustic tags (e.g., V5), including the V6-4X tag used in the Stipulation Study.**

After we checked for abnormalities, we placed the still-anesthetized steelhead into a holding cradle treated with a 25% solution of Stress Coat®. Handling fish causes damage to the fish's slime coat, and Stress Coat® replaces the fish's natural slime coat with a synthetic one, thereby reducing stress. We irrigated the fish's gills with water containing 20 mg/L of MS-222 through a soft rubber tube to maintain anesthesia during surgery.

We then assessed the scale condition of the steelhead on the most compromised side of the fish. We noted scale condition as Normal, Partial, or Descaled. We defined normal scale condition as the loss of less than 5% of scales on one side of the steelhead. We defined partial descaling as the loss of 6–19% of scales on one side of the steelhead. We classified steelhead as descaled if they had lost 20% or more of the scales on one side of the fish. Descaled fish likely suffer from compromised osmoregulatory ability. We placed descaled fish in a reject bucket and did not tag them.

Using a micro-scalpel equipped with a 5 mm blade, we made a 3–5 mm-long incision to one side of the mid-ventral line immediately anterior to the pelvic girdle. We inserted the acoustic tag into the body cavity through this incision. We then closed the incision with two or three simple interrupted sutures using Vicryl Plus 4-0 suture material to form the sutures (Figure 2-7). During the final stages of surgery, we switched the gill irrigation water supply from the MS-222 maintenance solution to supersaturated oxygen rich fresh water to begin the recovery process. Once the surgical procedure was completed, we moved the fish to a recovery bucket that provided 130% to 150% dissolved oxygen for a minimum of 10 minutes.

While fish were recovering, we used a VEMCO mobile tracking receiver (VR100) to verify that each transmitter was functioning properly. We recorded tag validation data for each fish. After the recovery period and tag validation were complete, we transferred the tagged steelhead to 68-L totes (Figure 2-8). We placed three steelhead in each labeled tote, and we subsequently loaded the tote into a fish transport tank that was attached to a flatbed truck. During loading and prior to transport, we maintained water temperature and oxygen levels inside the transport tank by pumping water into the tank from the hatchery raceway.

Figure 2-7 Tagging and suturing of a typical steelhead.

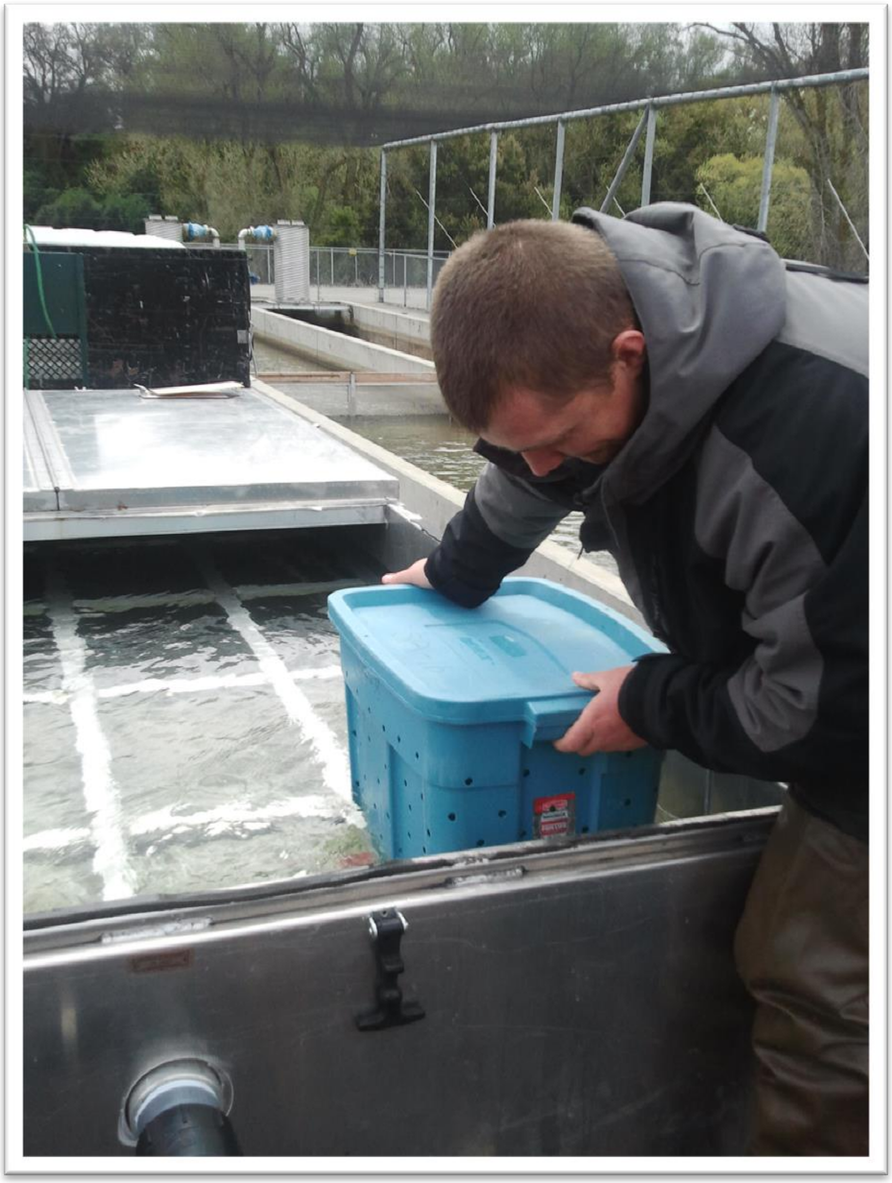


Figure 2-8 Loading tagged juvenile steelhead into the transport tank.

2.3.2 STEELHEAD TAGGING EVALUATION

Survival and delayed mortality of tagged fish are important factors to consider in any tagging study. To monitor the effects of surgical implantation of acoustic tags on fish mortality, we surgically implanted dummy tags into nine steelhead for each of the three tagging events. We transported the dummy-tagged steelhead to the Department's Collection, Handling, Transport, and Release (CHTR) facility for holding and observation. We surgically implanted dummy tags into these fish using the same methods (handling, data collection, tagging, recovery, transport, etc.) as for fish with active acoustic tags. We kept the three groups of dummy-tagged fish in three separate aerated holding tanks and fed them once daily. On June 5, 2012, we evaluated these fish for tag retention and healing. Because we evaluated all of the fish on the same day, each of the groups had been held for different lengths of time following tag implantation (Table 2-2). We euthanized each control group of steelhead and made external and internal observations to evaluate healing and recovery. We took photographs and recorded observations on a standardized data sheet.

Each of the three control groups began with nine steelhead (Table 2-2). There was one mortality from Release Group 1 within 24 hours after transfer to the CHTR facility. Release Groups 1 and 2 each had a single mortality later in the holding period when water temperature spiked upward due to an improperly functioning water chiller at the CHTR facility. Except for one fish in Group 1 that had fungus on the tail and fins, the tagged steelhead appeared healthy when evaluated. We observed no fungal infections on any other fish from any of the other control groups.

Table 2-2 Summary of control groups, holding period, and mortality.

Control Group	Holding Period (days)	Number of Fish		
		Tagged	Total Mortality	Evaluated
1	53	9	2[a]	7[b]
2	37	9	1[a]	8
3	23	9	0	9

Notes:

[a] One mortality from each of Group 1 and Group 2 was related to an improperly functioning water chiller and was not considered a tagging mortality.

[b] One fish had fungus infection on fins and tail at time of evaluation.

We examined suture sites and rated those sites on a scale from 0 (no irritation) to 4 (ulcerated). The group that had had tags implanted most recently, Group 3 at 23 days, showed ulcerated sites for 8 of 9 fish. After 37 days, Group 2 had 56% of the suture sites showing irritation ranging from slight redness (1) to ulcerated (4). Related to the irritation rates was the presence or absence of the sutures. After 53 days, Group 1 showed no irritation at any of the suture sites for fish without suture presence. In Group 1, the only steelhead to show ulceration at the suture site was the single fish of the group that still retained the sutures. The other six steelhead in that group did not have sutures remaining and did not show irritation. About half of the total sutures in Group 2 were missing after 37 days, and half of the fish in this group showed no irritation. Five steelhead from Group 2 had lost one suture and the second suture was still present. In this situation the site around the remaining suture showed signs of irritation and ulceration of the tissues. Group 3 only had one steelhead that showed no irritation, and this was the only fish whose sutures were not present. The remaining steelhead in the group had sutures in place, and these sites were ulcerated.

We reviewed and rated the incision sites on a scale of 0 to 4 for incision closure, where 0 was completely closed with no overlap and 4 was where the incision was completely open or overlapped. The results indicated that similar to irritation, the longer the time since tagging, the higher the rate of closure. All of Group 1 showed complete incision closure. Group 2 had 50% completely closed with 38% rated as partially closed (a 1 on the scale), and 12% were half open or overlapped (a 2 on the scale). Two-thirds of Group 3 were completely closed with the other third rated as partially closed (a 1 on the scale). Of the incisions that were less than completely closed, the musculature layer was fully apposed, but the dermal layer had not joined together.

We then dissected the dummy-tagged steelhead to observe the tags and how the tags interacted with tissues and organs. In 24 total tagged control group fish, 71% of the tags were located directly under the incision, 17% were located anterior to the incision, and 12.5% of the tags were located posterior to the incision. When looking for tag encapsulation, we observed that for tags in Group 1, 28.5% were not encapsulated, 57% were encapsulated in a transparent membrane, and 14% (1 tag) were encapsulated in an opaque membrane. Group 2 had 62.5% of the tags encapsulated in a transparent membrane and 37.5% encapsulated in a partially transparent membrane. Group 3 had only 33% of the tags encapsulated in a transparent membrane and the remaining 67% were not encapsulated.

A prime concern for proper internal healing is the apposition of the peritoneum. Twenty-three (23) of the 24 steelhead showed complete apposition of the peritoneum, and one steelhead had 75% of the incision that was apposed. This one fish had moderate inflammation in the section of the peritoneum that had not apposed. The rest of the steelhead, all with complete apposition, showed no internal incision irritation.

We evaluated each dummy-tagged fish for the presence of organ and internal tissue damage caused by either the suturing procedure or the tag itself. We observed no damage to internal tissues or organs in Groups 1 or 2, while Group 3 showed evidence of organ inclusion in the sutures, which was present in five of the nine fish. In addition, four of the nine fish in this group also showed some organ damage caused by the tag resting inside the pyloric caeca.

In conclusion, the suture material appeared to cause tissue irritation and ulceration around the incision site. The longer the time post-surgery, the more likely the suture was no longer present and the less likely there was irritation. While the sutures are considered absorbable, what appeared to be happening in the study fish was that the sutures were expelled. They became progressively looser and closer to the surface and were eventually completely expelled from the body. This process allowed the suture tag ends and knots to rub on the skin surface, causing the observed irritation. Based on the steelhead we observed, sutures were starting to be expelled somewhere between 23 and 37 days with most shed after 57 days.

2.3.3 TRANSPORT AND RELEASE OF ACOUSTIC TAGGED STEELHEAD

We transported totes containing three tagged steelhead each in a large aluminum tank from the Mokelumne River Fish Hatchery to Buckley Cove (near Stockton) where we offloaded the totes. We supplemented the water with bottled oxygen during transport.

After arriving at Buckley Cove, we tempered the water in each tote by gradually adding river water to allow steelhead to adjust to the warmer river water temperature. Once water temperatures had adjusted, we transported the totes on a small boat (Figure 2-9) from Buckley Cove to a houseboat moored in the San Joaquin River (Figure 2-10). At the houseboat, we emptied seven totes (for a total of 21 steelhead) into each of the eight net pens. The eight net pens were constructed of a polyvinyl chloride (PVC) conduit frame covered with netting and were approximately 1.2 x 1.2 x 1.2 m in dimension (Figure 2-11). We used pool noodles around the top of the net pen to float the net pen in the W-shaped dock. Each net pen encompassed an approximate volume of 1,800 L, and we specially designed each net pen to allow the natural flow-through of water. We designed the net pens for release of tagged fish in slow-moving water only. We held tagged steelhead in the net pens for a minimum of 48 hours prior to release to fully acclimate to the conditions in the river. Prior to release, we visually checked the fish in each net pen for mortalities. We removed one dead steelhead from net pen #2 on May 1, 2012 prior to release (Release Group 2). We observed no other mortalities. Following the minimum 48-hour acclimation period, we released one net pen of steelhead every 3 hours until all eight net pens of tagged steelhead had been released. We released the tagged steelhead by opening the net pen lid and tipping the net pen over. All releases occurred within 24 hours after they were started at approximately at 3:00 pm on the first day of the release period. A total of 501 healthy tagged steelhead were released with functional tags. Of the 501 tags, 166 were released in Group 1, 167 in Group 2, and 168 in Group 3. Average lengths (mm) and weights (grams) of the 501 steelhead are listed in Table 2-3.

Table 2-3 Lengths and weights of 501 tagged steelhead that were observed to be healthy prior to release and had functional tags.

Release Group	Release Dates	Number of Fish Tags	Fish Length (mm)		Fish Weight (g)	
			Mean	Standard Error	Mean	Standard Error
1	April 15-16, 2012	166	223.0	1.4	106.8	2.2
2	May 1-2, 2012	167	230.5	1.4	119.0	2.5
3	May 15-16, 2012	168	241.5	1.5	157.3	3.1

Figure 2-9 **Totes containing acoustically tagged steelhead on-board a boat that transported the totes to floating net pens on a houseboat.**

Figure 2-10 **The houseboat with the floating net pens.**

Figure 2-11 Floating net pens used to hold experimental release groups of steelhead prior to release.

2.3.4 TAG LIFE AND BURDEN

The V6-4X acoustic coded transmitters (tags) used in the Stipulation Study were compatible with the tags and receivers used with other study programs throughout the Delta, including the 2012 Six-Year Study.

Data on the duration of battery lives of this type of tags were from the currently unpublished 2012 battery life studies provided by Dr. Josh Israel (pers. comm.). For the tag-life study, more than 90 tags were activated and observed the length of time that tags functioned. This study had two replicates with one starting on April 6, 2012 (i.e., trial 1) and the other starting on May 25, 2012 (i.e., trial 2). In total, 48 and 45 tags were used in trials 1 and 2, respectively. One tag in trial 2 was not functioning properly. The tag worked correctly for >70 days at the pulses per minute (ppm) code (even), but not the high residence receiver (HRR)/ppm hybrid code, therefore this tag did work correctly for being detected on VR2Ws, but not correctly for being detected on HRR-cabled receivers (J. Israel, pers. comm.). This tag was removed from the tag life vitality study and was not considered in the calculation of the following numbers. For trial 1, the average tag life was 78.4 days (standard error [SE]=0.4 days). For trial 2, the average tag life was 76.6 days (SE=1.6 days). The minimum tag life was 58.5 and 19.5 days for trial 1 and 2, respectively. In both trials, 100.0% of the tags examined in the tag life vitality study lasted longer than the monitoring period for the Stipulation Study (15 days).

Each V6-4X acoustic coded transmitter weighed approximately 1 gram. To examine the tag burden for acoustically tagged steelhead in the study, tag weight (1 gram) was divided by steelhead weight and expressed as a percentage. The tag burden for Release Group 1, Release Group 2, and Release Group 3 was 1.0% (SE<0.1%), 0.9% (SE<0.1%), and 0.7% (SE<0.1%), respectively. The average tag burden for live steelhead released for this study was 0.9% (SE<0.1%).

2.4 STUDY ASSUMPTIONS

The assumptions used in the 2012 Stipulation Study are listed below.

1. Tagging did not affect survival.
2. There was little or no mortality from handling.
3. Tag expulsion was minimal.
4. The tag burden (weight of tag:weight of smolt) was appropriate.
5. Tags did not affect swimming performance or predator avoidance.
6. The tag burden was similar across release groups.
7. Tag detection probability at each location was high (>80%).
8. Detection probability at the acoustic receiver arrays did not vary between release groups.
9. The influence of predation on steelhead tags was minimal and did not bias results.
10. OMR flow differences between Group 3 and Groups 1 and 2 were sufficient to test hypotheses.
11. Treating Release Group 3 versus Groups 1 and 2 as different OMR flow treatments was appropriate despite OMR flow fluctuations during release groups.
12. Hatchery steelhead and wild steelhead smolts behaved similarly.
13. Hatchery steelhead were appropriately used as wild steelhead "sentinels."
14. Tag life was sufficient for the duration that data were collected.

As noted by the 2012 IRP LOO Annual Review (Kneib et al. 2012), the credibility and reliability of the findings in any analysis depend substantially on whether or not assumptions are reasonable. Therefore, we examined the validity of many of these assumptions.

Tagging did not affect survival.

Although it is unknown how steelhead tagging affected survival of fish once released, proper tagging procedures were followed during tagging and release, leading to very limited mortality prior to release. Of the 505 tagged steelhead, only one died prior to release. Of the 27 steelhead implanted with dummy tags and monitored in a controlled environment for tagging survival, only one steelhead died within 24 hours after tagging. Two other steelhead died after 24 hours as a result of an improperly functioning water chiller. Except for one control fish with a fungal infection, all other steelhead appeared healthy following tagging.

There was little or no mortality from handling.

Only one of the 505 tagged steelhead died prior to release, indicating that handling mortality was very low. Although an unknown amount of handling mortality could occur shortly after release, in the model, we only used data for tags that were detected at array 1 to minimize the impact.

The tag burden (weight of tag:weight of smolt) was appropriate.

The tag burden was less than 1%, which is far under the acceptable threshold level in similar studies. A maximum of 2% tag to body weight ratio is typically accepted as per the literature recommendations. The SOP for this study would have allowed a 5% tag to body weight ratio (equaling a 20 gram fish). The average weight of fish used in the study was 128 grams.

Tags did not affect swimming performance or predator avoidance.

We did not conduct an analysis to examine this and do not know if predator avoidance was affected. However, because the tag burden was far below the acceptable threshold level, we feel we met this assumption. Also, the speed at which steelhead tags moved in the system (Section 4.2.3) provided evidence that swimming performance was not hindered by tag burden.

The tag burden was similar across release groups.

The tag burden was different between groups, as the heaviest fish were observed in Release Group 3 (mean=157 grams), and lightest fish were observed in Release Group 1 (mean=107 grams). This was due to steelhead feeding and growing during the study, as fish released for Release Group 3 had the longest time to grow prior to being tagged and released. While the tag burden was different across release groups, the tag burden was far below the acceptable threshold for all release groups.

Tag detection probability at each location was high (>80%).

While the analyses conducted in the multistate mark-recapture model do not require high detection probabilities, it is important for analyses conducted without the model. As estimated by the multistate model (Sections 4.2.1 and 4.2.2), detection probability was high (>80%) for arrays 7, 20, 22, and 24. However, detection probability was much lower for arrays 2 and 21, with detection probabilities of 64% and 12% at the array-level for arrays 2 and 21, respectively (see Section 4.2.1). Although detection probability was low for these arrays, the model accounts for detection probabilities and the model was able to converge. In Sections 4.3.1 and 4.3.3, using Manly-Parr estimates (described in Section 4.2.1), detection probabilities for the dual arrays used in those analyses (arrays 3, 11, 15, and 19) were 100% at array-level for all release periods that we could estimate.

Detection probability at acoustic receiver arrays did not vary between release groups.

For all arrays used in the analyses and where detection probabilities could be estimated, detection probability did not vary between release groups. Detection probabilities did not vary across release groups for arrays 2 and 7 (Section 4.2.1) and arrays 3, 11, 15, and 19 (Sections 4.3.1 and 4.3.3). We did find that detection probability varied across release groups at array 6 (Section 4.2.1); however, array 6 was replaced with array 7 for all study analyses.

The influence of predation on steelhead tags was minimal and did not bias results.

As found in previous Delta acoustic studies (SJRGA 2011), some steelhead tags may have been present inside predators rather than tagged free-swimming steelhead smolts. When analyzing acoustic tagging data of Chinook salmon smolts for the 2010 VAMP study, attempts were made to distinguish between tagged salmon smolts and those tags that had been consumed by predators (SJRGA 2011). A filter was applied to all tag detections based on assumed behavioral differences between Chinook salmon smolts and predators. For example, Chinook salmon smolts were expected to move with the flow while actively migrating downriver, while predators were not expected to show such unidirectional movement. Although the best available information was used to inform the predator filter, no validation was performed, and therefore its accuracy is unknown.

Utilizing the predator filter developed for Chinook salmon would likely produce biased results as juvenile steelhead may behave differently than Chinook salmon. We could have attempted to create our own predator filter for distinguishing between steelhead and predators, however, the inability to validate such a steelhead predator filter would have introduced an unknown amount of uncertainty to the study results. Given the larger size of juvenile steelhead, predation on steelhead tagged in this study may have been less frequent than in other mark-recapture studies that used smaller Chinook salmon. However, the true influence of predation on study findings is unknown.

OMR flow differences between Release Group 3 and Release Groups 1 and 2 were sufficient to test hypotheses.

Because the original goal of achieving three distinctly different OMR flow treatments was not met, we analyzed the data as two release groups, with Release Groups 1 and 2 pooled as a less negative OMR flow treatment, and Release Group 3 as a more negative OMR flow treatment, as recommended by the 2012 IRP LOO Annual Review (Kneib et al. 2012). Therefore, study results should reflect how the range of OMR flows during the study influenced fish behavior in each OMR flow treatment group. However, because OMR flows only spanned approximately 70% of the proposed range of flows, and historical flows have been much more negative than observed during the study, it is uncertain how well study results extrapolate to OMR flow conditions outside of the range observed. In addition, only two replicates of less negative OMR flows and a single replicate of more negative flows were examined. Therefore, additional replications of stable OMR flows across the examined range and beyond are recommended to corroborate study findings and understand how OMR flows affect fish behavior and survival.

Treating Release Group 3 versus Release Groups 1 and 2 as different OMR flow treatments was appropriate despite OMR flow fluctuations during release groups.

The average OMR flows following release for each release group was used to assign Release Groups 1 and 2 to a less negative OMR flow treatment and Release Group 3 to a more negative OMR flow treatment. However, OMR flows varied following each release, especially after a point in the second week when the trigger was activated and flows were brought to -1,250 cfs. This occurred on April 24, May 11, and May 26, 2012 for Release Groups 1, 2, and 3, respectively. We believe that the impact of these flow fluctuations was minimal because the majority of steelhead tags in all release groups moved through the Delta before these dates.

Hatchery steelhead and wild steelhead smolts behave similarly.

The assumption that tagged hatchery steelhead are a valid proxy for wild steelhead was likely violated because of behavioral differences between hatchery and wild fish, as observed in other Central Valley studies. Wild steelhead have been shown to behave differently than hatchery steelhead (e.g., Chittenden et al. 2008; and reviews by Melnychuk et al. 2010 and Drenner et al. 2012). An alternative would have been to use tagged wild steelhead instead of hatchery surrogates. However, using wild steelhead would be challenging. This species is threatened, and collecting large numbers of wild steelhead smolts would be difficult if not impossible.

Hatchery steelhead were appropriately used as wild steelhead “sentinels.”

The arrival of steelhead tags implanted in hatchery steelhead in the interior Delta (Railroad Cut) was used as a trigger for altering export pumping levels and thereby protecting wild steelhead from entrainment to CVP and SWP. However, as described in the previous assumption, hatchery steelhead likely behave differently than their wild counterparts; the arrival timing of tagged steelhead was highly dependent on their release date, and likely different than when wild steelhead arrived. Although this assumption was likely violated, it is unknown to what extent wild steelhead arrival timing differed from tagged hatchery steelhead. Future studies should be completed to understand how well tagged hatchery steelhead mimic the behavior of their wild counterparts.

Tag life was sufficient for the duration that data were collected.

A tag life study showed that failure occurred on average after 78.4 days (SE=0.4 days) in the first trial and 76.6 days (SE=1.6 days) in the second tag life study. One of the tags stopped functioning after 19.5 days but all the tags included in this study, which were all tags that were detected on both types of acoustic receivers from the beginning, were functioning for the entire 15-day period that steelhead tags were monitored during the study.

3 DATA MANAGEMENT

CHAPTER SUMMARY:

In the spring of 2012, we initiated a mark-recapture experiment to examine the survival and movement patterns of acoustically tagged juvenile steelhead emigrating through the Delta. The dataset was for the 501 live fish released with tags that were known to be functional. We also received detection data for Stipulation Study steelhead tags that were detected by receivers deployed for the Six-Year Study. We performed quality assurance/quality control (QA/QC) on the data and produced a Microsoft (MS) Access 2010 database file composed of four separate table objects:

1. Fish measurements, release, and transport.
2. Release dates, timing, and corresponding group number.
3. Filtered Stipulation Study fish detection data.
4. Receiver codes, identification, station names, and arrays.

We only examined steelhead tags that were detected within 15 days of release. We processed these data by filtering out detection records which were: (1) at a date/time prior to the release date, (2) beyond the 15 days of release date, and/or (3) detected at a receiver only once within the ± 30-minute time-frame.

3.1 DATABASE DESIGN AND IMPLEMENTATION

This section describes the Access database, which included data on acoustically tagged steelhead from the 2012 Stipulation Study. The database included detection data from acoustic receiver arrays as shown in Figure 2-3. Where possible, data descriptions described in this report are included within the Access database under data field definitions and table comments. We received a set of fish detection data from all receiver arrays shown in Figure 2-3 on August 24, 2012. We corrected all fish detection data for time drift using VUE software. We also received detection data for Stipulation Study tagged fish detected from the receivers deployed by the 2012 Six-Year Study (care of Josh Israel, Reclamation). By the end of February of 2013, we received all the data from receivers of the arrays.

We checked and verified the tagging, transport, release, and detection data in the database to ensure quality control. We checked for duplicated serial numbers and tag-IDs per release and bucket/tote IDs, checking for blank records for each field, the units used for fish measurements, and reviewing comments noted by the field biologist to ensure that they were properly represented in the data (e.g., failed tag, functioning tag number, dummy serial number, fish behavior prior to release). We flagged data found to be questionable or unmatched to field notes and sent those data to Kevin Clark (field implementation lead) to verify. Because of the limited file size available in the Access database, we excluded fish data for non-Stipulation Study tagged fish from this database.

Data were provided in the MS Access database in four separate table objects:

01_TagData&FishInfo contains data on fish measurements, release, and transport (Table 3-1).

02_ReleaseDates_GroupNum contains specific data on release dates, timing, and corresponding group number (Table 3-2).

03_All_FishDetection_within15dayofrelease contains all the detection data for all fish for the entire study (Table 3-3).

04_Receiver_Array contains receiver codes, ID numbers, station names, and arrays service details (Table 3-4).

We structurally organized and shaped the data in several table objects into a relational database. Table objects were connected via "one-to-many" relationships between tables (Figure 3-1). For example, the table 01_FishSerialNum and 02_FishSerialNum_TagCodes had a one-to-many relationship indicating that each fish serial number had two fish tag ID numbers, but each fish tag ID number had only one unique fish serial number. This approach maintained the integrity, quality, and accessibility of the large dataset. Our approach also prevented duplicates in fish tag serial numbers or tag ID numbers, and allowed efficient accessibility and flexibility of records necessary when creating data queries to conduct the analysis in the following chapter.

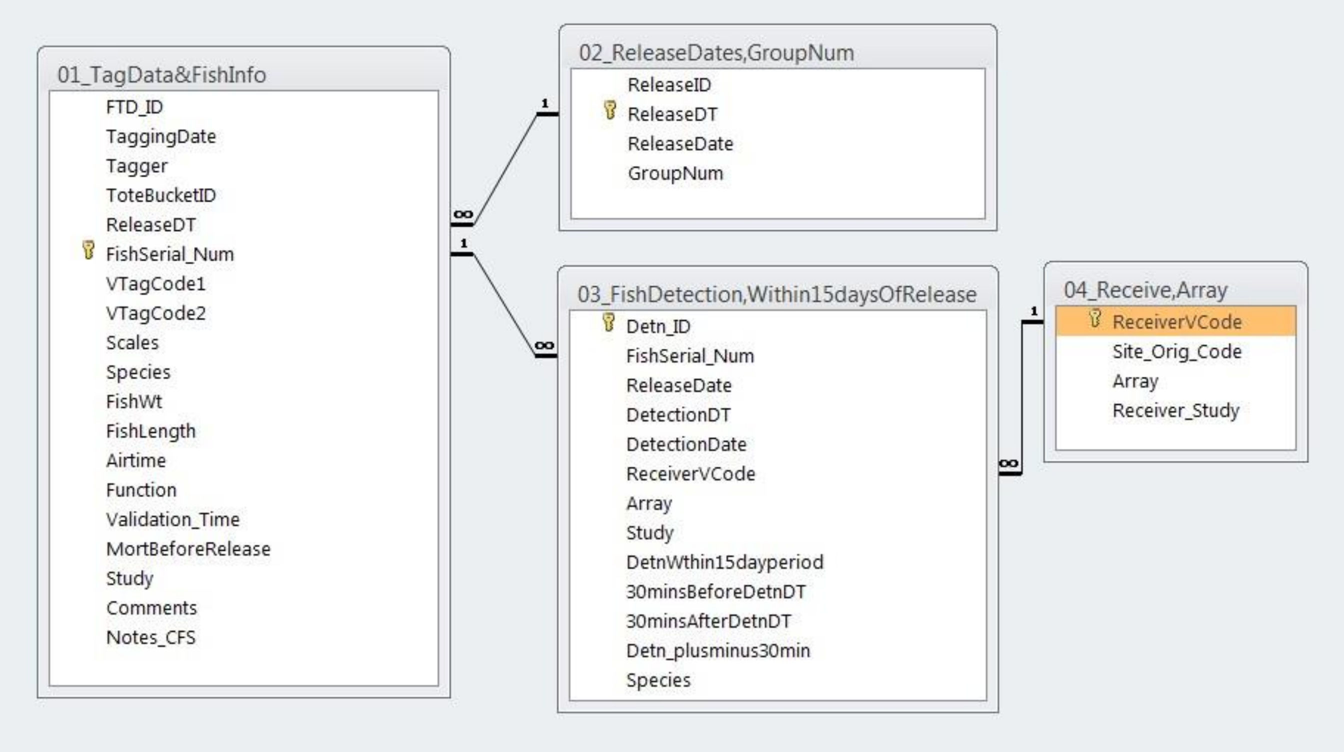


Figure 3-1 Tables and relationships used in the Stipulation Study database.

01_TAGDATA&FISHINFO

The Access table "01_TagData&FishInfo" included fish measurements, tagging, transport, and release date data. A total of 505 fish were acoustically tagged and of these, one steelhead died. All live acoustically tagged fish were released. Four steelhead were recorded to have non-functioning tags prior to release, although we subsequently detected one fish that was thought to have a non-functional tag. Therefore, the dataset consists of 501 fish with functioning tags, as included in Table 3-1.

Table 3-1 List of field names, data types, and descriptions in 01_TagData&FishInfo.

Field Name	Data Type	Description
FTD_ID	Text	Tagging data row ID assigned by Cramer Fish Sciences (CFS). FTD stands for **F**ish **T**agging **D**ata row ID.
TaggingDate	Date/Time	Tagging date.
Tagger	Text	Name of the field biologist who tagged fish.
ToteBucketID	Text	Tote and/or Bucket ID.
ReleaseDT	Date/Time	Release Date and Time.
FishSerial_Num	Number	VEMCO Fish tag serial number.
VTagCode1	Number	VEMCO tag code 1.
VTagCode2	Number	VEMCO tag code 2.
Scales	Text	Fish scales condition; N=Normal (loss of ≤5% scales on one side of the steelhead), P=Partial (loss of 6-19% of scales on one side of the steelhead), D=Descaled (lost ≥20% or more of the scales on one side of the fish, and were not being tagged due to compromised osmoregulatory ability).
Species	Text	Species code: STH=steelhead (in Stipulation Study, all were STH smolts).
FishWt	Number	Fish weight (grams).
FishLength	Number	Fish fork length (mm).
Airtime	Date/Time	Time when the fish was out of the water during tagging. Airtime started when the steelhead was removed from the bucket containing MS-222, and airtime stopped when the fish was placed into a recovery bucket.
Function	Text	Y: tag was verified to be functioning; N: tag was verified to be not functioning.
Validation_Time	Date/Time	Time at which the tag function was verified by a biologist.
MortBeforeRelease	Number	Number of fish mortality observed before fish release (all live fish herein since we excluded one dead fish).
Study	Text	Study name (all Stipulation Study).
Comments	Text	Field notes.
Notes_CFS	Text	Data notes by CFS.

02_RELEASEDATES_GROUPNUM

The Access table "02_ReleaseDates_GroupNum" included the list of release dates and times, and the associated group number. Acoustically tagged fish were released in three groups at Buckley Cove: April 15–16 (Group 1), May 1–2 (Group 2), and May15–16 (Group 3), 2012 (Table 3-2).

Table 3-2 List of field names, data types, and descriptions in 02_ReleaseDates_GroupNum.

Field Name	Data Type	Description
ReleasedID	Autonumber	Data row ID.
ReleasedDT	Date/Time	Release date and time.
ReleaseDate	Date/Time	Release date.
GroupNum	Number	Group number assigned to each release date.

03_ALL_FISHDETECTION_WITHIN15DAYOFRELEASE

The Access table “03_ALL_FISHDETECTION_WITHIN15DAYOFRELEASE” included Stipulation Study fish detection data within the 15 days of release (Table 3-3). These data were processed by filtering out detection records that were: (1) at a date/time prior to the release date, (2) beyond the 15 days of release date, and/or (3) detected at a receiver only once within the ± 30 minutes time-frame.

Table 3-3 List of field-names, data type, and description for table 03_All_FishDetection_within15dayofrelease.

Field Name	Data Type	Description
Detn_ID	Text	Data row ID from “raw detection data” (from the raw database, which is not described herein). These IDs were used as cross-reference ID between the filtered Stipulation Study detection data and the original “raw” detection data. Detn_IDs were assigned by CFS. In addition, Detn_IDs with labels “DtnStip_### (e.g., DtnStip_86524)” indicated detection data of tagged Stipulation Study fish downloaded from the Stipulation Study and “6yr_#### (e.g., 6yr_940896) and #### (e.g., 1003)” detection data for Six-Year Study receivers.
FishSerial_Num	Number	VEMCO fish tag serial number of an individual fish.
ReleaseDate	Date/Time	Release date and time.
DetectionDT	Date/Time	Detection date and time.
DetectionDate	Date/Time	Detection date.
ReceiverVCode	Number	VEMCO receiver serial code.
Array	Number	Array numbers assigned by CFS.
Study	Text	Study name (in the case herein, all Stipulation Study).
DetnWthin15dayperiod	Text	Yes: detection data within the 15 days of release (all yes herein since these are all filtered detection data).
30minBeforeDetnDT	Date/Time	30-mins before the detection date/time of an individual fish at a receiver.
30minAfterDetnDT	Date/Time	30-mins after the detection date/time of an individual fish at a receiver.
Detn_plusminus30min	Number	Count of detection hits within the ± 30 minutes time-frame from the recorded detection date/time of an individual fish at a receiver (only records with series of detection hits >1 at a receiver).
Species	Text	STH: steelhead smolt (Stipulation Study tagged fish are all steelhead smolts).

04_RECEIVER_ARRAY

The Access table "04_Receiver_Array" included the list of receiver codes (old and new), original station name, array, and the project that deployed the receivers. Geographic coordinates and visualizations of telemetry stations and a release site were plotted on a map and saved in KMZ file format.

Table 3-4 List of field names, data types and descriptions in 04_Receiver_Array.

Field Name	Data Type	Description
ReceiverVCode	Number	VEMCO receiver serial number/code.
Site_Orig_Code	Text	Site/station name assigned originally by Kevin Clark.
Array	Number	Arbitrary array number assigned by CFS.
Receiver_Study	Text	A project name that deployed the receiver.

TAG DATA USED IN EACH ANALYSIS AND FULL DETECTION HISTORIES

Appendix B (*Crosswalk Table of Tag and Dependent Analysis*) shows what tags were used in what analysis. This appendix presents the data used to produce the figures and results for the analyses in this report (Chapter 4).

This page intentionally left blank.

4 RESULTS

CHAPTER SUMMARY:

We performed the analyses at three spatial levels: system, route, and junction-level. For the system-level analysis, we displayed the data in a variety of tables, figures, and a web-based data viewing tool. We found that a physically based model (the DSM2 Hydro PTM) was unable to predict the movement of steelhead tags, because the model greatly underestimated steelhead tag movement rates through the study area. Using a t-test, we found that steelhead tags were traveling significantly greater distances 3 days and 7 days after their release than particles in the PTM. Steelhead tag movement patterns seemed to exhibit limited STST behaviors, which could explain why particles traveled less distance after both 3 and 7 days. Using binomial tests, we also found that diurnal and nocturnal movement patterns might be occurring, but these patterns were location-specific.

For the route-level analysis, we developed a multistate model to estimate route-specific transition probabilities (a measure of steelhead tags that went through a route and survived, so the complement of route-specific transition probability is not just mortality but the probability of mortality, using a different route, or not reaching Chipps Island in 15 days), route-specific survival probabilities (the complement of survival is the probability of mortality or not reaching Chipps Island in 15 days), and overall survival probability. Data were pooled for all release groups as the model using data from a single release group (e.g., Release Group 3) did not converge. This model with the pooled data allowed us to estimate route-specific transition probability for each of the six different routes (all routes started downstream of Buckley Cove and ended at Chipps Island):

- The route-specific probability via Turner Cut was 7.0% (SE=1.6%).
- The route-specific probability without using Turner Cut was 24.8% (SE=2.0%).
- The route-specific probability via Turner Cut and the SWP was 0.5% (SE=0.5%).
- The route-specific probability via the SWP without using Turner Cut was 0.2% (SE=0.2%).
- The route-specific probability via Turner Cut and the CVP was 19.6% (SE=2.8%).
- The route-specific probability via CVP without using Turner Cut was 31.7% (SE=1.9%).

Overall survival to Chipps Island was 50.2% (SE=2.0%). Route-specific survival probability for the Turner Cut route was 27.0% (SE=3.0%). Route-specific survival probability for the Mainstem route was 56.7% (SE=2.4%). The model estimated that the majority of steelhead tags (77.6%, SE=1.6%), continued along the San Joaquin River, and 22.4% (SE=1.6%) of the steelhead tags were entrained into the interior Delta at the Turner Cut junction. Using an analysis of variance (ANOVA), we found that travel times for steelhead tags differed between these two routes, with steelhead tags reaching Chipps Island more rapidly for the Mainstem route compared to the steelhead tags that successfully reached Chipps Island using the Turner Cut route (using these routes as defined in the model). The faster migration of steelhead tags using the Mainstem route was consistent with higher survival for this route.

We found no evidence that the routing of steelhead tags at the three junctions along the San Joaquin River (Columbia Cut, Middle River, and Turner Cut) was affected by the OMR flow treatment levels examined in this study. When the data were examined using two release groups (less negative vs. more negative OMR flows), we found no significant differences for the OMR levels tested in this study. In the analysis of steelhead tags arriving into Clifton Court Forebay or the CVP, we found that while not significant, on average the proportion of water arriving at an export facility was higher at the facility for the period of time when a steelhead tag was arriving at the facility that first detected it.

We wanted to determine whether steelhead tags at Railroad Cut were more likely to move north away from the SWP and CVP intakes after the adaptive management option was triggered and less negative OMR flows were observed. However, when we examined if adaptive management trigger was effective, we were unable to successfully complete the test due to the small sample size of steelhead tags passing through Railroad Cut after the management option was observed to take effect (N=7). Yet, there was marginally significant (statistical test values over 0.05 but less than 0.1) evidence that steelhead tags at Railroad Cut were more likely to move north in less negative (Groups 1 and 2) OMR flows than in more negative (Group 3) OMR flow conditions. We examined nine predictor variables in separate tests. Only the test that used average OMR flow on the day that the steelhead tag was first detected downstream of Railroad Cut was found to be significant.

4.1 SYSTEM-LEVEL ANALYSES

In this section, we present the analysis of system-level movement patterns of steelhead tags both descriptively through spatial display of tag data, and statistically by examining key large-scale hypotheses. We begin with the descriptive results where tag data are displayed in a suite of figures, tables, and a web-based tool. We describe the percentage of steelhead tags detected at each array, where last detections occurred, the residence time at each array, the final fate of steelhead tags at each array, and provide a web-based tool displaying tag detection histories. In Sections 4.1.6, 4.1.7, and 4.1.8, we examine three statistical hypotheses to determine how well movement of simulated particles mimicked steelhead tag behavior, whether tags exhibited selective movement behavior in relation to tides, and how steelhead tag movement related to time of day.

Although we did not account for detection probability at arrays when calculating system-level results, we assume that detection probability did not vary between release groups, and therefore relative differences in spatial patterns of tags across release groups reflect the true movement of tags. In later results sections (Sections 4.2.1, 4.3.1, and 4.3.3), we examined if detection probability varied across release groups for arrays with dual receivers (2, 3, 6, 7, 11, 15, and 19) and found that detection probability only varied across release groups for array 6. Therefore, except for array 6, relative differences in the spatial pattern of tags can likely be attributed to release group differences and not to differences in detection probabilities. Also, most arrays had high detection probabilities (>80%) so system-wide biases in tag spatial patterns are very unlikely when examining system-level results.

4.1.1 RELATIVE TAG DETECTION AT ARRAYS

We examined the spatial pattern of steelhead tags detected by release group, by depicting the percentage of tags detected at each array (Figure 4-1 and Table 4-1). The results generally showed a decreasing number of individual steelhead tags detected the farther away tags moved from the release location of Buckley Cove, indicating a declining number of tags as they traveled downstream, most likely resulting from mortality. No consistent pattern between release groups was evident, indicating that the OMR flows tested likely had minimal effect on the general movement patterns of steelhead tags during the study.

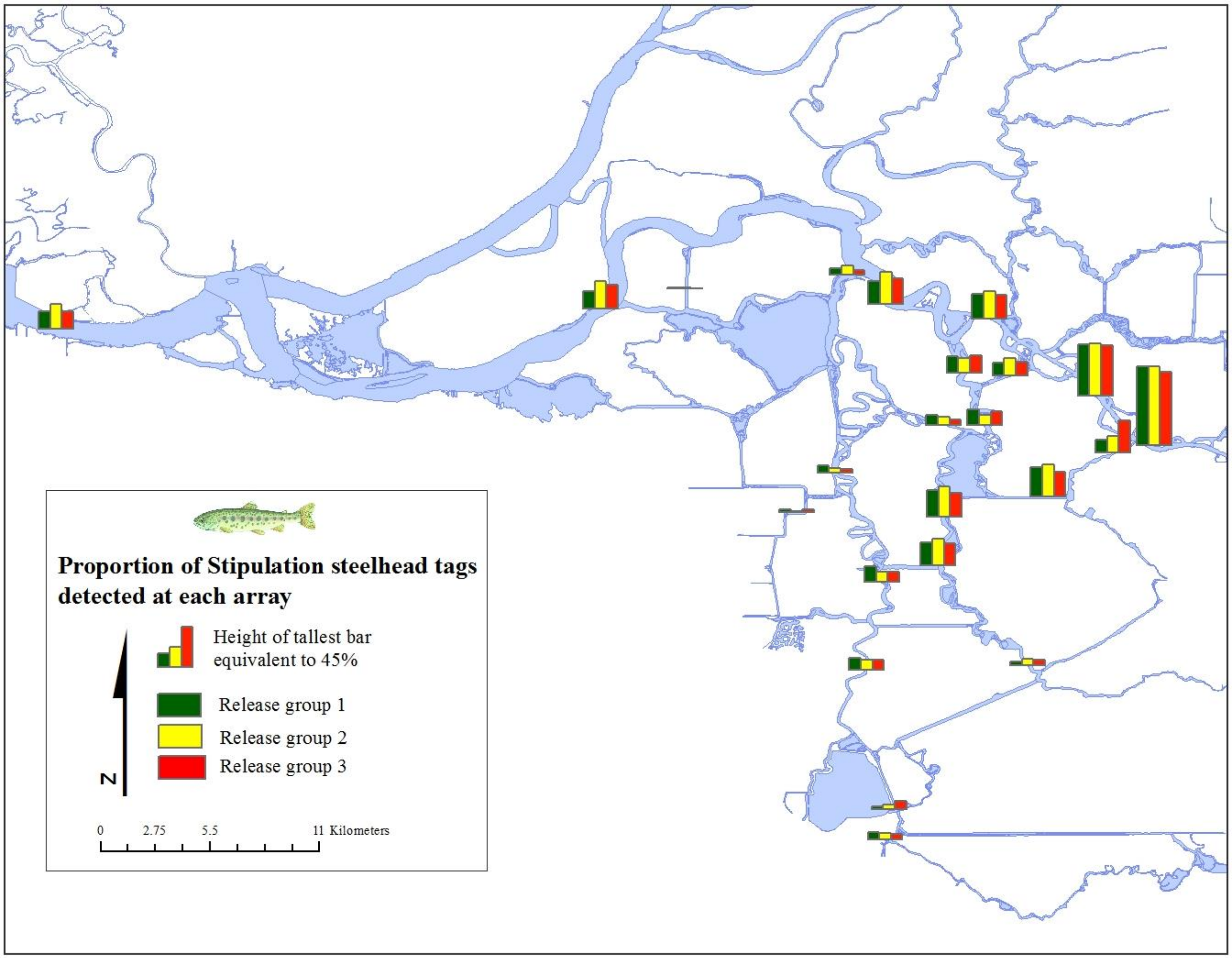


Figure 4-1 **Percentage of individual steelhead tags detected in each array by release group.** See Table 4-1 for the source data.

Table 4-1 Number and percentage of Stipulation Study steelhead tags detected in each array by release group. The percentage was calculated as the number of tags detected at that array from that release group divided by the total number of tags released for the release group. The total number of tags released was 166, 167, and 168 for Release Groups 1, 2, and 3, respectively.

Array	Number of Tags Detected			Percentage of Tags Detected (%)		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
1	147	149	139	88.6	89.2	82.7
2	95	98	96	57.2	58.7	57.1
3	45	51	44	27.1	30.5	26.2
4	42	60	48	25.3	35.9	28.6
5	13	17	9	7.8	10.2	5.4
6	24	31	61	14.5	18.6	36.3
7	55	61	47	33.1	36.5	28.0
8	50	58	46	30.1	34.7	27.4
9	44	51	42	26.5	30.5	25.0
10	6	12	11	3.6	7.2	6.5
11	23	33	26	13.9	19.8	15.5
12	29	20	27	17.5	12.0	16.1
13	30	27	32	18.1	16.2	19.0
14	18	16	10	10.8	9.6	6.0
15	14	8	6	8.4	4.8	3.6
16	29	18	18	17.5	10.8	10.7
17	6	2	5	3.6	1.2	3.0
18	0	0	0	0.0	0.0	0.0
19	22	18	18	13.3	10.8	10.7
20	6	9	15	3.6	5.4	8.9
21	13	11	10	7.8	6.6	6.0
22	33	52	45	19.9	31.1	26.8
23	1	1	0	0.6	0.6	0.0
24	33	47	33	19.9	28.1	19.6

4.1.2 LAST DETECTION AT ARRAYS

We examined the spatial pattern of where steelhead tags were last detected by release group, by depicting the percentage of tags last detected at each array (Figure 4-2 and Table 4-2). The largest number of final detections occurred at the Chipps Island array, providing evidence that a large proportion of steelhead tags migrated through the system successfully. The next highest percentage was at the first array. The large percentage of last detections at the first array may indicate high mortality, possibly due to high predation or handling mortality following release. No consistent pattern between release groups appeared evident, indicating that the OMR flows tested likely were not driving the general patterns seen in the final detection data.

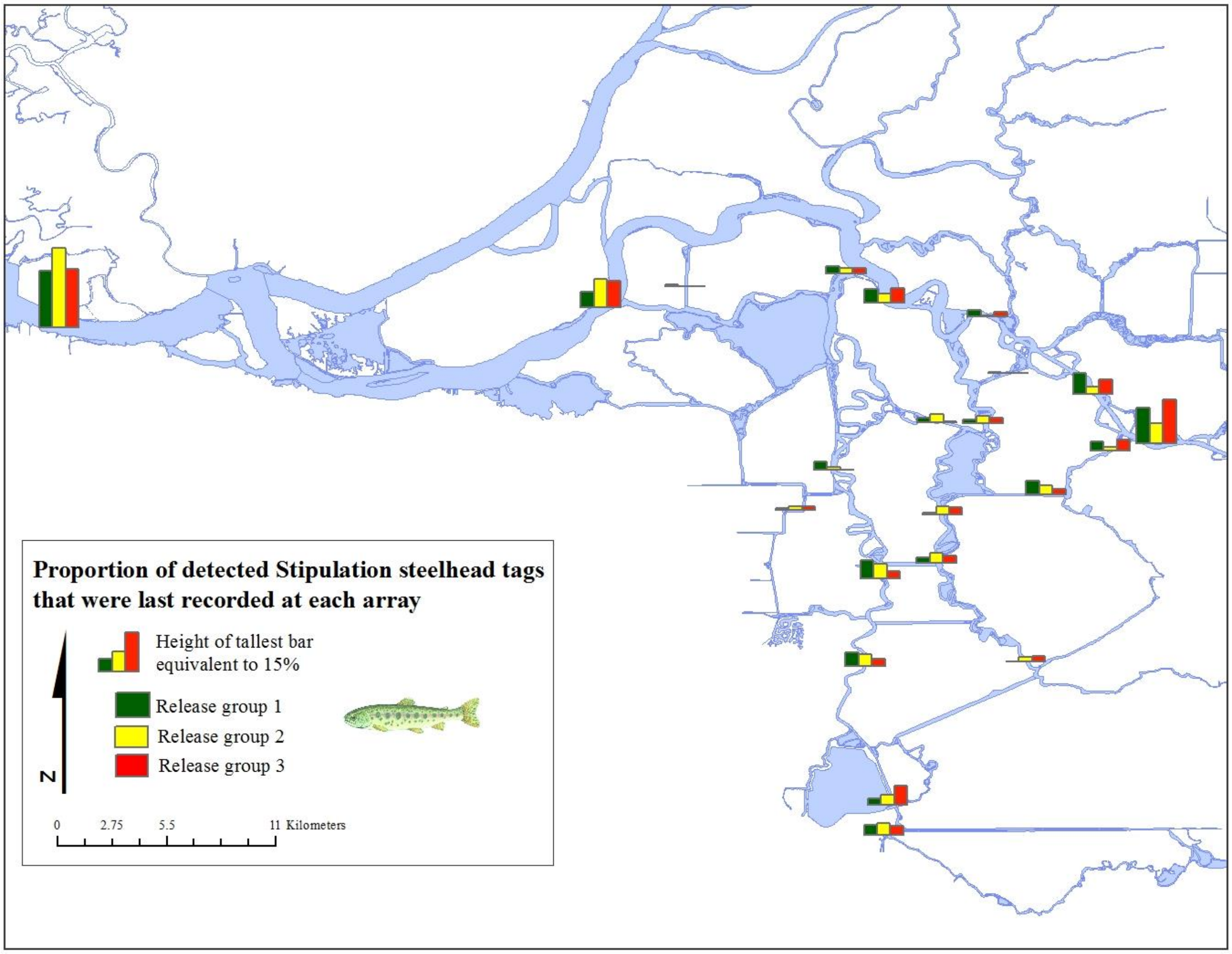


Figure 4-2 Percentage of steelhead tags last detected at each array by release group. The distribution of last detections indicates areas where fish mortality occurred or where tags left the area of receiver coverage. See Table 4-2 for the source data.

Table 4-2 Number and percentage of steelhead tags last detected at each array by release group. Each tag was only counted at the single array where the tag was last detected. The percentage was calculated as the number of tags last detected at that array divided by the total number of tags from that release group that were detected at any array. The total number of tags detected at any array was 150, 152, and 145 for Release Groups 1, 2, and 3, respectively.

Array	Number of Tags Detected			Percentage of Tags Detected (%)		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
1	21	12	25	14.0	7.9	17.2
2	12	4	8	8.0	2.6	5.5
3	4	1	3	2.7	0.7	2.1
4	8	5	8	5.3	3.3	5.5
5	4	3	3	2.7	2.0	2.1
6	5	2	6	3.3	1.3	4.1
7	8	5	3	5.3	3.3	2.1
8	1	5	4	0.7	3.3	2.8
9	3	6	4	2.0	3.9	2.8
10	0	3	3	0.0	2.0	2.1
11	1	0	0	0.7	0.0	0.0
12	2	4	3	1.3	2.6	2.1
13	0	0	0	0.0	0.0	0.0
14	3	5	1	2.0	3.3	0.7
15	5	2	0	3.3	1.3	0.0
16	11	9	4	7.3	5.9	2.8
17	1	2	2	0.7	1.3	1.4
18	0	0	0	0.0	0.0	0.0
19	8	7	4	5.3	4.6	2.8
20	4	6	11	2.7	3.9	7.6
21	6	7	5	4.0	4.6	3.4
22	9	17	15	6.0	11.2	10.3
23	1	0	0	0.7	0.0	0.0
24	33	47	33	22.0	30.9	22.8

4.1.3 RESIDENCE TIME AT ARRAYS

We examined the spatial pattern of residence time at each array by release group, by depicting the average time spent by steelhead tags at each array (Figure 4-3 and Table 4-3). The results indicated that the time between first and last detections at each array was generally consistent among arrays, except for the arrays located at the radial gates of Clifton Court Forebay (array 20) and CVP (array 21). On average, steelhead tags spent more time at arrays 20 and 21 than any other array in the study system, indicating that steelhead tags may have been consumed by a predator and defecated at these locations, trapped, or delayed from leaving the vicinity of those arrays. No consistent pattern between release groups was evident, indicating that OMR flows tested were not likely driving the general patterns seen in tag residence time. See Table 4-3 for the source data.

A potential bias influencing array residence time results was the 15-day filter applied to steelhead tag data. By cutting off detection data beyond 15 days, array residence time may be underestimated, especially at more downstream arrays that were not reached until later in the study period (i.e., arrays 20–24). However, since the majority of steelhead tags that successfully traveled through the system did so in less than 7 days (see Section 4.2.3), the proportion of tags being detected at Chipps Island eliminated by the 15-day filter was small (6%). Also, very large residence times observed at arrays 20 and 21 provided evidence that underestimation of residence time was likely not a problem.

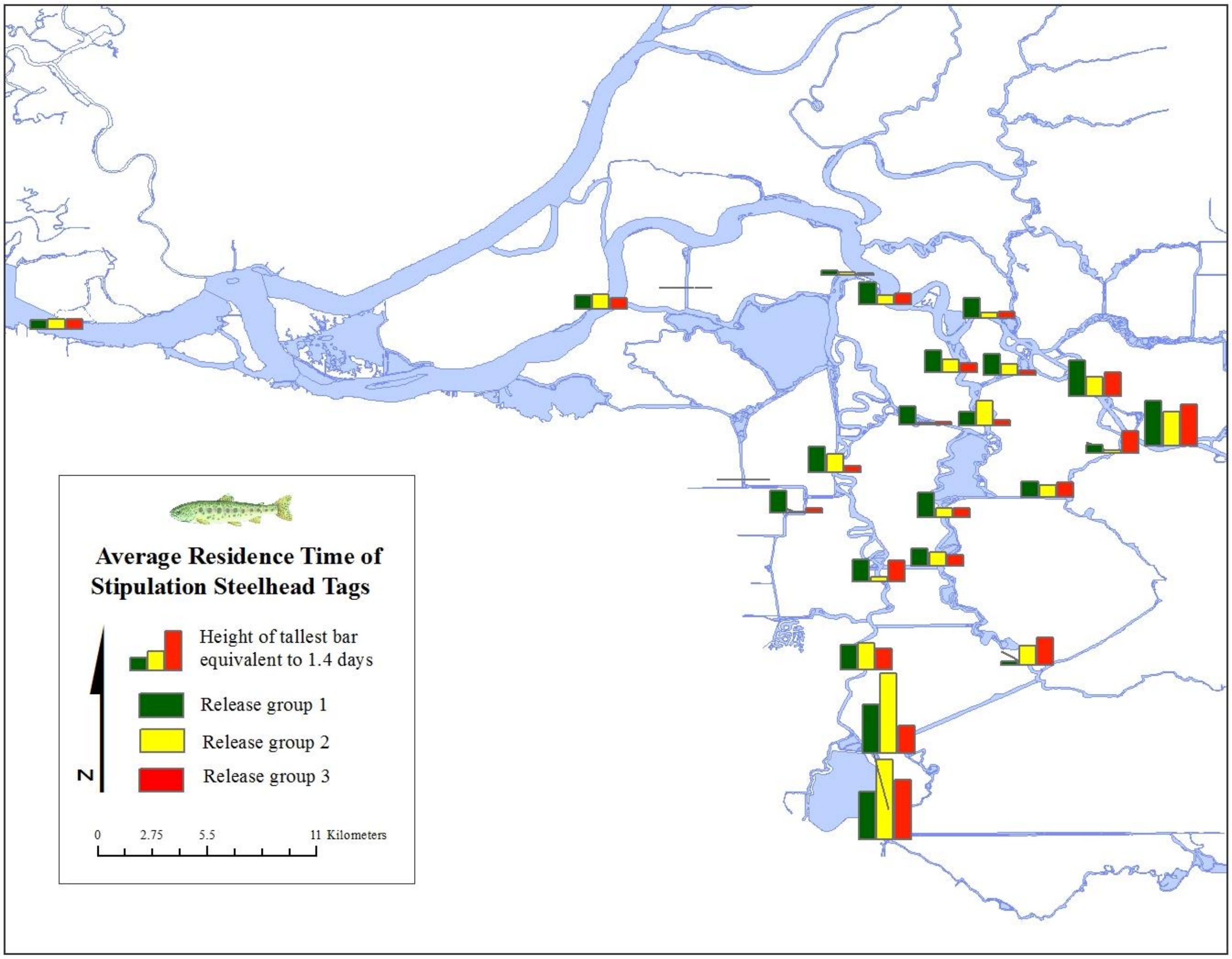


Figure 4-3 Average residence time of steelhead tags at each array by release group. Residence time is equal to the difference between the last and first detections of individual tags. See Table 4-3 for the source data.

Table 4-3 Sample sizes, average, minimum, and maximum values of residence time (days) of steelhead tags at each array by release group. Residence time of a tag is equal to the difference between the last and first detection at each array.

	Release Group 1				Release Group 2				Release Group 3			
Array	N	Average	Minimum	Maximum	N	Average	Minimum	Maximum	N	Average	Minimum	Maximum
1	147	1.5	<0.1	14.6	149	1.2	<0.1	14.3	139	1.4	<0.1	12.4
2	95	1.2	<0.1	13.3	98	0.7	<0.1	14.0	96	0.8	<0.1	11.3
3	45	0.7	<0.1	9.7	51	0.2	<0.1	2.5	44	0.2	<0.1	2.4
4	42	0.7	<0.1	10.2	60	0.3	<0.1	1.7	48	0.4	<0.1	1.8
5	13	0.2	<0.1	1.1	17	0.1	<0.1	0.7	9	0.1	<0.1	0.3
6	24	0.3	<0.1	2.7	31	0.1	<0.1	1.2	61	0.7	<0.1	13.4
7	55	0.5	<0.1	4.6	61	0.4	<0.1	4.5	47	0.5	<0.1	10.7
8	50	0.8	<0.1	8.4	58	0.3	<0.1	4.0	46	0.3	<0.1	1.6
9	44	0.6	<0.1	10.2	51	0.5	<0.1	10.2	42	0.4	<0.1	5.5
10	6	0.1	<0.1	0.3	12	0.7	<0.1	3.6	11	0.9	<0.1	5.8
11	23	0.7	<0.1	8.9	33	0.4	<0.1	7.3	26	0.2	<0.1	1.1
12	29	0.5	<0.1	2.9	20	0.8	<0.1	9.4	27	0.2	<0.1	3.1
13	30	0.8	<0.1	5.4	27	0.5	<0.1	7.6	32	0.3	<0.1	3.4
14	18	0.7	<0.1	6.8	16	0.1	<0.1	0.6	10	0.1	<0.1	0.7
15	14	0.9	<0.1	3.2	8	0.6	<0.1	1.8	6	0.2	<0.1	0.9
16	29	0.8	<0.1	3.8	18	0.2	<0.1	0.8	18	0.7	<0.1	7.4
17	6	0.8	<0.1	3.1	2	<0.1	<0.1	<0.1	5	0.1	<0.1	0.4
18	0	-	-	-	0	-	-	-	0	-	-	-
19	22	0.9	<0.1	5.5	18	0.9	<0.1	9.0	18	0.7	<0.1	6.2
20	6	1.7	<0.1	7.8	9	2.7	<0.1	10.5	15	1.0	<0.1	7.0
21	13	1.6	0.2	7.3	11	2.7	0.2	10.2	10	2.0	0.1	12.0
22	33	0.5	<0.1	1.9	52	0.5	<0.1	3.9	45	0.4	<0.1	1.8
23	1	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	0	-	-	-
24	33	0.3	<0.1	0.9	47	0.3	<0.1	1.4	33	0.3	<0.1	2.0

4.1.4 FINAL FATE AT ARRAYS

We examined the spatial pattern of the final fate of steelhead tags at each array by release group, by depicting the last location of tags at each array. The data from each array were categorized and displayed based on final fate (i.e., the location of last detection of a steelhead tag) at four final destinations (CVP, SWP, Chipps Island, or in-river) for each of the three release groups (Figure 4-4 to Figure 4-6 and Table 4-4). Successfully salvaged steelhead tags were recorded at Chipps Island (array 24). The steelhead tags recorded as having the SWP destination were last detected at array 20, which is the array upstream and downstream of the radial gates of Clifton Court Forebay. Array 21 was located at the CVP and was the last detection location for steelhead tags that entered the CVP. The steelhead tags recorded as in-river were not detected last at array 20, 21, or 24.

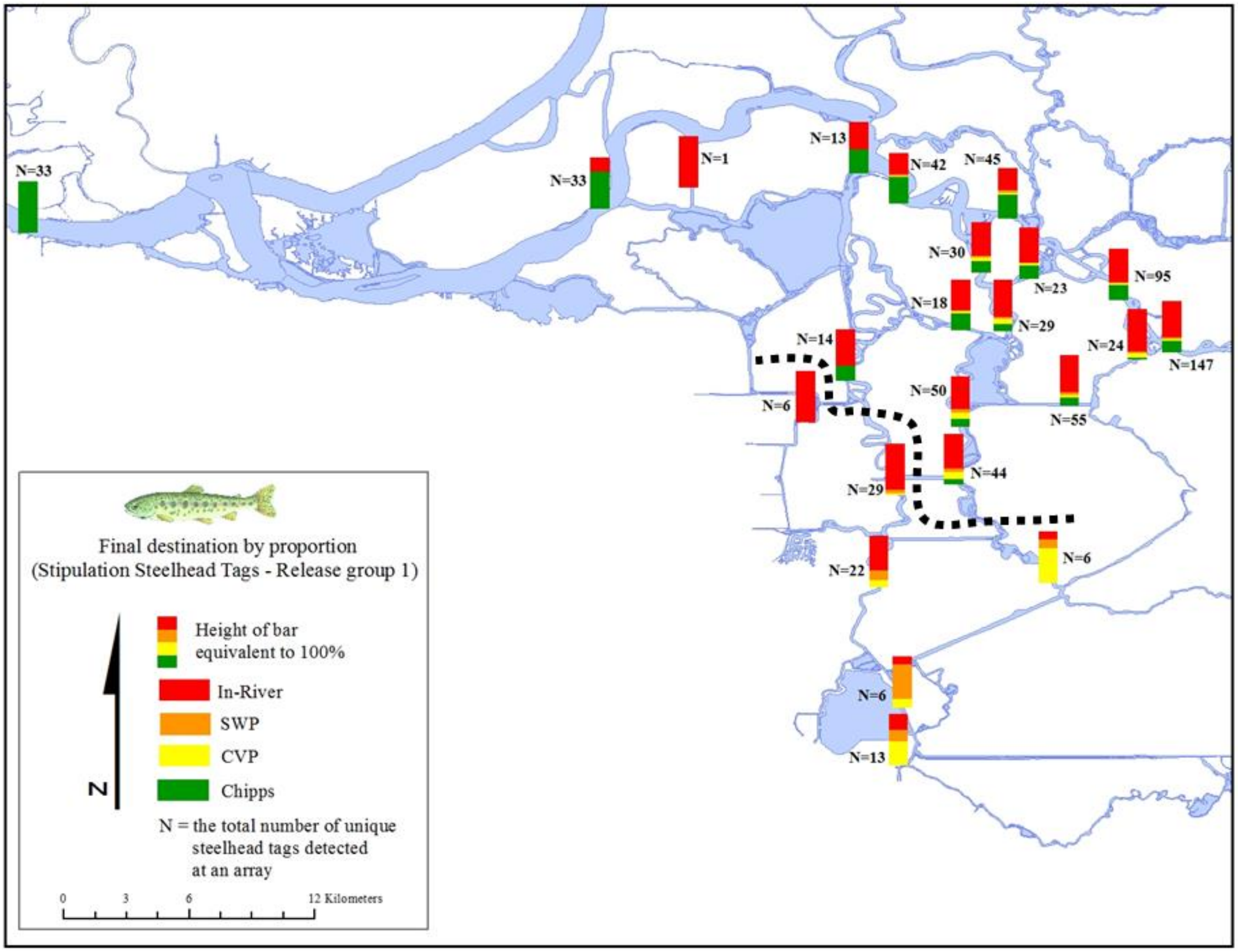


Figure 4-4 For each array, the proportion of steelhead tags from Release Group 1 last detected at one of four destinations (CVP, SWP, Chipps Island, or in-river). No tags were successfully salvaged for Release Group 1. The sample size (N) for each array is denoted next to each bar. See Table 4-4 for the source data. The dashed black line indicates the "point of no return," the southern-most locations where at least one steelhead tag successfully arrived at Chipps Island without assistance through salvage.

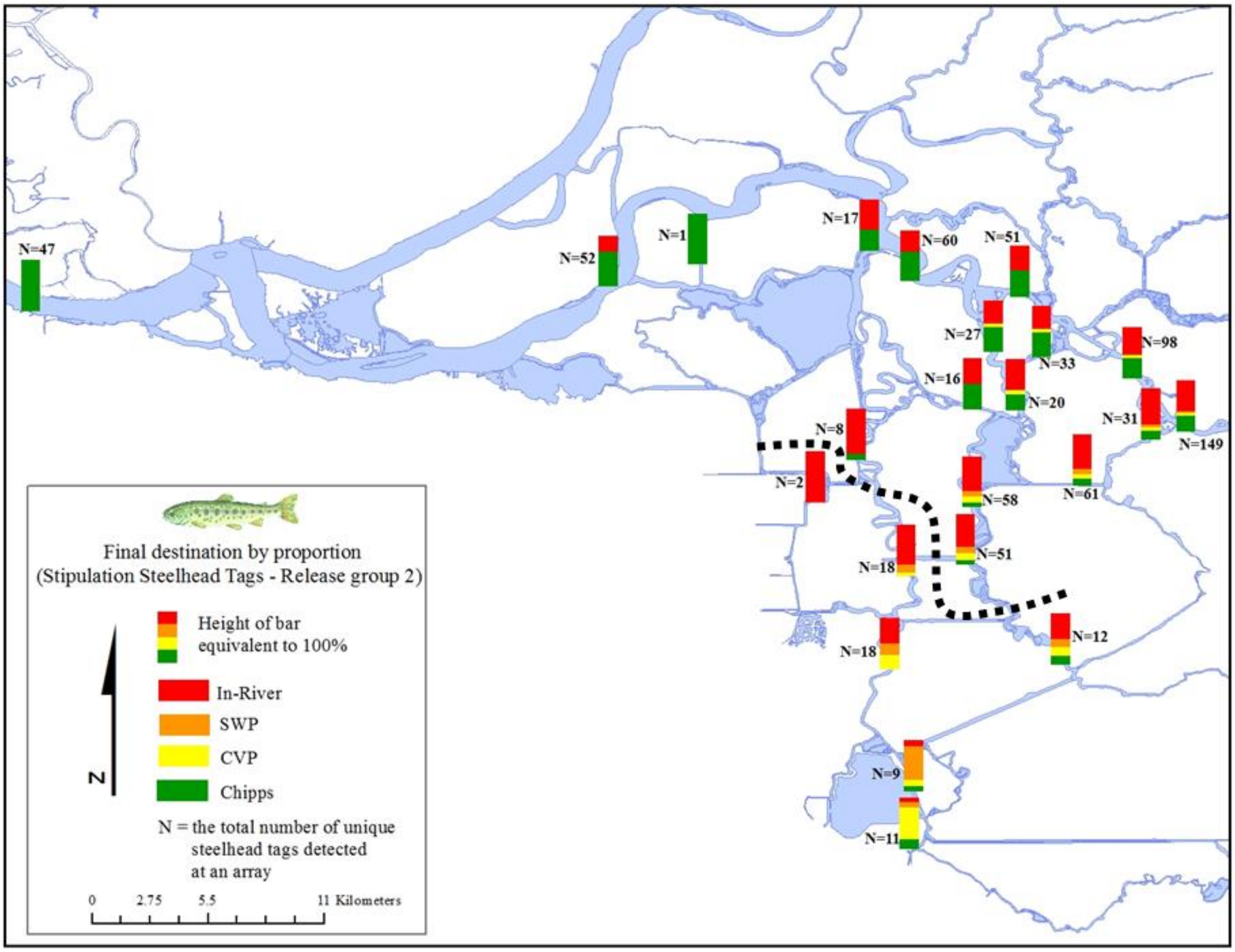


Figure 4-5 **For each array, the proportion of steelhead tags from Release Group 2 last detected at one of four destinations (CVP, SWP, Chipps Island, or in-river).** Successfully salvaged tags were recorded at Chipps Island. The sample size (N) for each array is denoted next to each bar. See Table 4-4 for the source data. The dashed black line indicates the “point of no return,” the southern-most locations where at least one steelhead tag successfully arrived at Chipps Island without assistance through salvage.

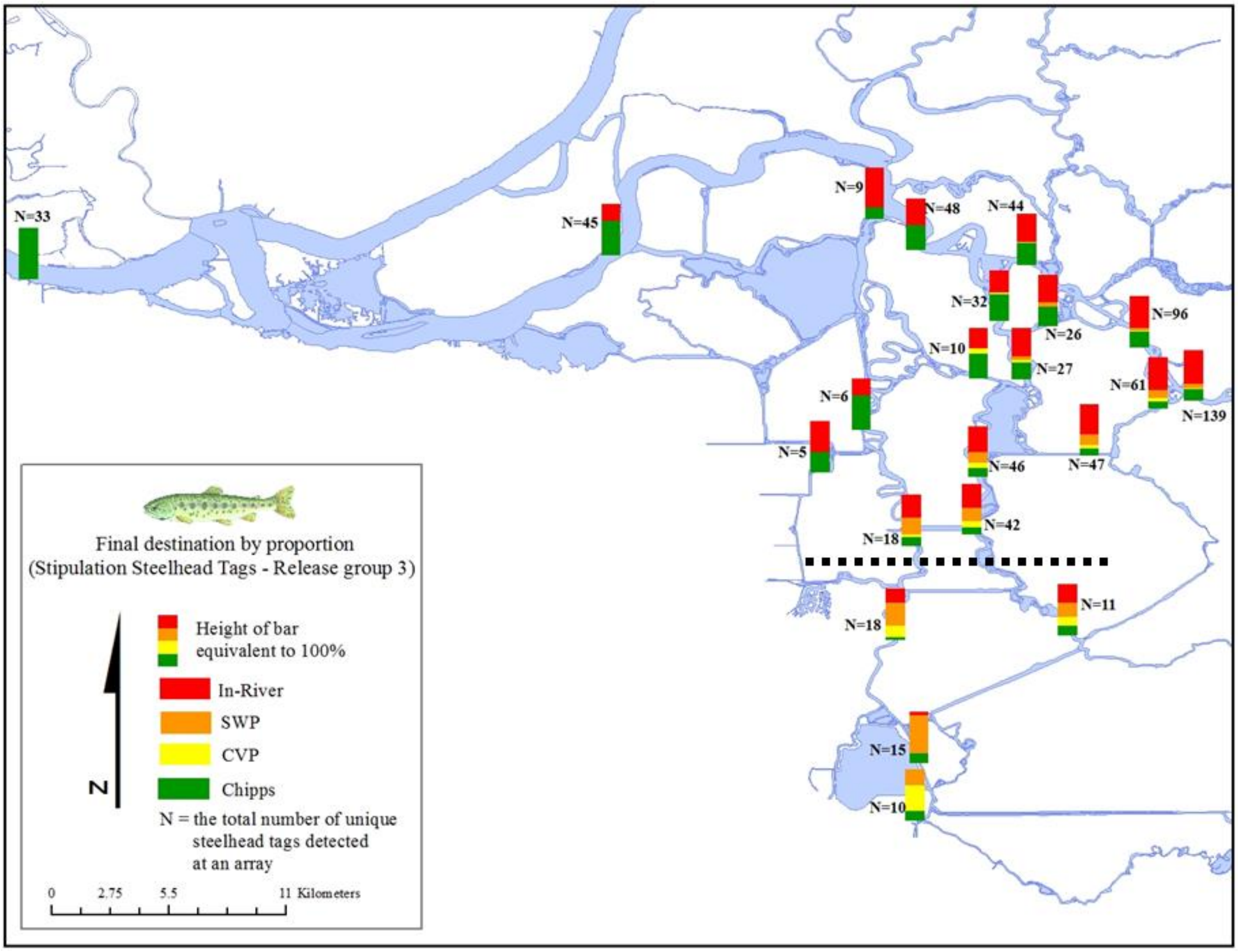


Figure 4-6 **For each array, the proportion of steelhead tags from Release Group 3 last detected at one of four destinations (CVP, SWP, Chipps Island, or in-river).** Successfully salvaged tags were recorded at Chipps Island. The sample size (N) for each array is denoted next to each bar. See Table 4-4 for the source data. The dashed black line indicates the “point of no return,” the southern-most locations where at least one steelhead tag successfully arrived at Chipps Island without assistance through salvage.

Table 4-4 For each array, the percent of steelhead tags last detected at one of four destinations (CVP, SWP, Chipps Island, or in-river). Successfully salvaged tags were recorded at Chipps Island (array 24). The tags recorded as having the destination at SWP were last detected at array 20, which is the array upstream and downstream of the radial gates of Clifton Court Forebay. The tags last detected at CVP were last detected at array 21. The tags recorded as in-river were not detected last at array 20, 21, or 24.

Array	Chipps Island			In-River			CVP			SWP		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
1	22.4	30.9	22.3	70.7	60.4	66.9	4.1	4.7	2.9	2.7	4.0	7.9
2	28.4	40.8	32.3	65.3	53.1	61.5	4.2	4.1	1.0	2.1	2.0	5.2
3	46.7	51.0	43.2	44.4	49.0	54.5	4.4	0.0	2.3	4.4	0.0	0.0
4	52.4	58.3	47.9	42.9	41.7	52.1	2.4	0.0	0.0	2.4	0.0	0.0
5	46.2	41.2	22.2	53.8	58.8	77.8	0.0	0.0	0.0	0.0	0.0	0.0
6	4.2	16.1	13.1	83.3	71.0	63.9	8.3	6.5	8.2	4.2	6.5	14.8
7	16.4	14.8	12.8	72.7	67.2	59.6	5.5	8.2	8.5	5.5	9.8	19.1
8	16.0	10.3	17.4	64.0	67.2	50.0	12.0	12.1	10.9	8.0	10.3	21.7
9	11.4	9.8	14.3	68.2	64.7	47.6	13.6	13.7	11.9	6.8	11.8	26.2
10	0.0	16.7	18.2	16.7	50.0	36.4	66.7	16.7	18.2	16.7	16.7	27.3
11	26.1	48.5	38.5	69.6	45.5	53.8	4.3	6.1	0.0	0.0	0.0	7.7
12	13.8	30.0	33.3	72.4	60.0	55.6	10.3	10.0	3.7	3.4	0.0	7.4
13	23.3	48.1	53.1	66.7	44.4	43.8	6.7	7.4	3.1	3.3	0.0	0.0
14	33.3	50.0	50.0	61.1	50.0	40.0	5.6	0.0	10.0	0.0	0.0	0.0
15	28.6	12.5	66.7	71.4	87.5	33.3	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	16.7	89.7	77.8	44.4	3.4	5.6	5.6	6.9	16.7	33.3
17	0.0	0.0	40.0	100.0	100.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	5.6	68.2	50.0	27.8	13.6	27.8	22.2	18.2	22.2	44.4
20	0.0	11.1	20.0	16.7	11.1	6.7	16.7	11.1	0.0	66.7	66.7	73.3
21	0.0	18.2	20.0	30.8	9.1	0.0	46.2	63.6	50.0	23.1	9.1	30.0
22	72.7	67.3	66.7	27.3	32.7	33.3	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

As expected, the proportion of steelhead tags last detected at Chipps Island or at either export facility (arrays 20 and 21) increased as tags approached each of these final destinations across all release groups (Figure 4-4 to Figure 4-6 and Table 4-4). In other words, as steelhead tags approached their final destination, the arrays closer to that destination showed a higher relative proportion of tags with that final destination. The proportion of tags at the export facilites that were successfully salvaged and were ultimately recorded at Chipps Island (indicated by green bar) was zero for Release Group 1, while successfully salvaged tags that were detected at the export facilities ranged from 11 to 20% for Release Groups 2 and 3. If OMR flows tested were driving salvage success, we would have expected salvage success to be different for Release Group 3 versus 1 and 2. However, the observed differences appeared to be driven by factors other than OMR flows.

Additionally, we wanted to examine the "point of no return" for steelhead tags by identifying at what point steelhead tags in the interior Delta no longer arrived at Chipps Island without assistance (through salvage operations at export facilities). For each release group figure (Figure 4-4 to Figure 4-6), we demarcated a line indicating the southern-most locations where at least one steelhead tag succesfully arrived at Chipps Island without assistance through salvage. If OMR flows tested had a large influence on the "point of no return" for steelhead, we would expect this line to move north for Release Group 3 versus 1 and 2, indicating a larger influence of pumping facilities when OMR flows were more negative.

The "point of no return" for steelhead tags was identical between Release Groups 1 and 2, and slightly more to the south for Release Group 3. This result is the opposite of our expectation that the more negative OMR flows occuring during Release Group 3 would lead to a larger zone of infuence of export pumping, with the "point of no return" moving more north. This finding indicated that the different levels of OMR flows examined in this study likely did not influence the ability of steelhead tags in the interior Delta to return to the Mainstem San Joaquin River and reach Chipps Island without assistance.

A potential bias influencing the "point of no return" demarcation was the small sample sizes of steelhead tags at interior Delta arrays. As indicated in Figure 4-1 and Table 4-1, the proportion of overall tags that reached arrays near the export facilities was very low. Therefore, our ability to precisely identify the "point of no return" line for each release group was limited.

4.1.5 WEB-BASED DETECTION HISTORY

A web-based dissemination tool was created to spatially display the full detection history of individual steelhead tags. The application was built in Shiny (RStudio Inc. 2013), which is a statistical package from RStudio for the program R (R Project 2013). The base map type used (e.g., terrain, satellite) and the size of the map can be controlled by the user (Kahle and Wickham 2013). The data can be sorted in a variety of ways, such as by serial number, by release group, or final detection location (export facilities and/or Chipps Island). The speed at which data can be displayed is also controlled by the user. As the application runs, static information is displayed in the top-right panel that includes the fish serial number, release group, release date, and whether it was detected at the export facilities and/or at Chipps Island. Below that panel is dynamic information that changes as the application shows each array where the steelhead tag was detected. This information includes the array number, the arrival and departure date and time for that array, number of detections, and residence time spent at the current array. The bottom-right panel displays the number of days since the tag was last detected at that array after its release. This web-based tool can be viewed at: http://glimmer.rstudio.com/hinkelman/stip-study/.

4.1.6 MOVEMENT OF STEELHEAD TAGS VERSUS SIMULATED PARTICLES

The distance that steelhead travel through the Delta in a certain amount of time not only determines their speed but also probably their survival (Sections 4.2.2 and 4.2.3). Therefore, managers are very interested in being able to predict the distance and destination of migrating steelhead smolts, as well as for other species. The DSM2 PTM was used to predict this information and design this experiment (NMFS 2012). Therefore, we developed the following hypothesis to examine if the DSM2 Hydro PTM model could predict the distance travelled by steelhead tags:

Hypothesis 4.1.6: The distance traveled by steelhead tags was not significantly different than the distance traveled by the passive particles.

METHODS FOR TESTING HYPOTHESIS 4.1.6

The distances traveled by simulated particles and steelhead tags observed 3 and 7 days after their release date were compared to evaluate the efficacy of using neutrally bouyant simulated particles to mimic steelhead tag behavior. The final location of a tag or a particle was the array where the tag or particle was last known to be on the day of interest (day 3 or 7) according to the acoustic telemetry data or the data generated from the DSM2 PTM for tags and particles, respectively. We used all arrays that were located where we had particle data. This led to excluding only a single tag that was detected at array 17 on the 3rd and 7th day (Table 4-5 and Table 4-6).

Particles were released in a similar fashion as were acoustically tagged steelhead. Simulated particles were injected at node 22 (Buckley Cove area) in the DSM2 PTM model at a rate of 1,250 every 3 hours for a total 10,000 particles over 24 hours starting at 3:00 pm on April 15, May 1, and May 15, 2012. The distance to an array that tags or particles were detected was estimated as the Euclidean distance from the array to the release site.

For particles, the DSM2 PTM model run data we were provided did not include the order of arrays that a particle went to nor the arrival and departures time of particles to individual receiver arrays. Thus, we were unable to calculate individual particle distances and had to rely on the relative particle flux across receiver arrays. The proportion of particles at each receiver array on the day of interest was scaled to the number of steelhead tags present on that day to have equal sample sizes of distances for particles and tags. Also, we assumed that all particles were released on the second day of a release group because we could not track individual particle histories.

A t-test was used to determine if significant differences existed between the distances traveled by the particles and steelhead tags. The datasets from the two days of interest (day 3 and 7) were analyzed separately.

Table 4-5 The Euclidean distance (km) of each array from the release site and the percentage of simulated particles and steelhead tags at that array on the third day after their release.

Array	Euclidean Distance from Release (km)	Particle Percentage	Tag Percentage
1	3.8	0.0	14.9
2	5.8	50.2	14.1
3	9.3	0.0	4.0
4	11.4	0.0	10.9
5	12.7	0.3	2.5
6	4.6	26.4	3.6
7	6.3	0.0	6.9
8	8.5	0.0	4.7
9	8.9	1.4	4.7
10	8.5	4.4	1.4
11	7.9	5.0	0.7
12	7.7	0.1	3.3
13	8.9	1.5	1.4
14	8.8	0.0	4.0
15	10.9	0.0	2.2
16	10.5	0.0	2.2
19	11.7	0.0	3.3
20	14.2	7.5	0.7
21	14.8	1.7	2.2
22	17.9	1.1	9.4
24	31.1	0.4	2.9

Table 4-6 The Euclidean distance (km) of each array from the release site and the percentage of simulated particles and steelhead tags at that array on the seventh day after their release.

Array	Euclidean Distance From Release (km)	Particle Percentage	Tag Percentage
1	3.8	0.0	11.8
2	5.8	2.3	6.9
3	9.3	0.0	0.7
4	11.4	0.1	5.6
5	12.7	1.0	0.0
6	4.6	0.2	2.1
7	6.3	0.0	4.9
8	8.5	0.0	4.2
9	8.9	8.4	2.8
10	8.5	11.7	2.1
11	7.9	6.9	2.8
12	7.7	10.7	4.2
13	8.9	43.1	0.7
14	8.8	0.7	2.8
15	10.9	0.0	5.6
16	10.5	1.0	3.5
19	11.7	0.0	2.8
20	14.2	10.1	6.3
21	14.8	2.7	4.2
22	17.9	0.1	9.0
24	31.1	1.0	17.4

RESULTS FOR THE HYPOTHESIS 4.1.6 TEST

As expected, steelhead tags and particles moved farther from the release site of Buckley Cove in relation to days from release (Figure 4-7 and Figure 4-8), as shown by the higher average distance traveled by particles and steelhead tags on day 7 compared to day 3. A t-test found that steelhead tags traveled significantly farther than the particles 3 and 7 days following release. After 3 days, steelhead tags traveled (9.5 km, SE=0.3 km, Table 4-5) significantly farther ($P<0.01$) compared to the particles (6.8 km, SE=0.2 km, Table 4-5). On average, particles only traveled 71.6% (6.8 km / 9.5 km) of the distance traveled by tags after 3 days (Figure 4-7). After 7 days, steelhead tags traveled (13.4 km, SE=0.8 km, Table 4-6) significantly farther ($P<0.01$) compared to the particles (9.5 km, SE=0.2 km, Table 4-6). On average, particles only traveled 70.9% (9.5 km / 13.4 km) of the distance traveled by steelhead tags after 7 days (Figure 4-8).

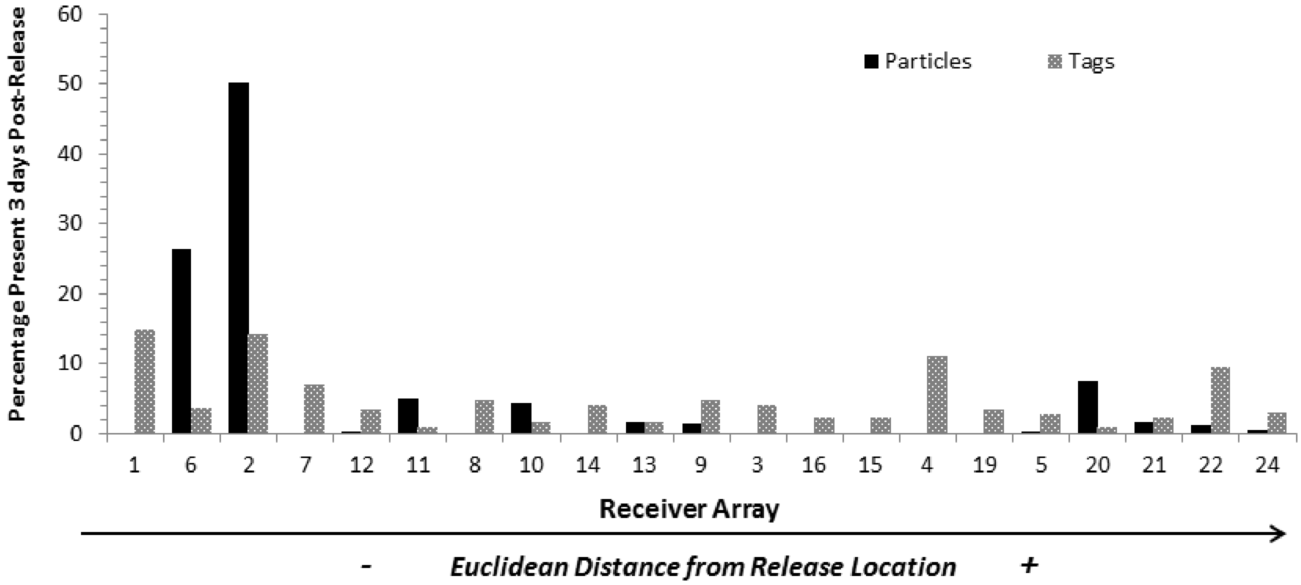


Figure 4-7 **The percentage of steelhead tags and simulated particles at the arrays on the third day after release.** Arrays are ordered from shortest Euclidean distance (left) to greatest (right) Euclidean distance (km) from the release site of Buckley Cove.

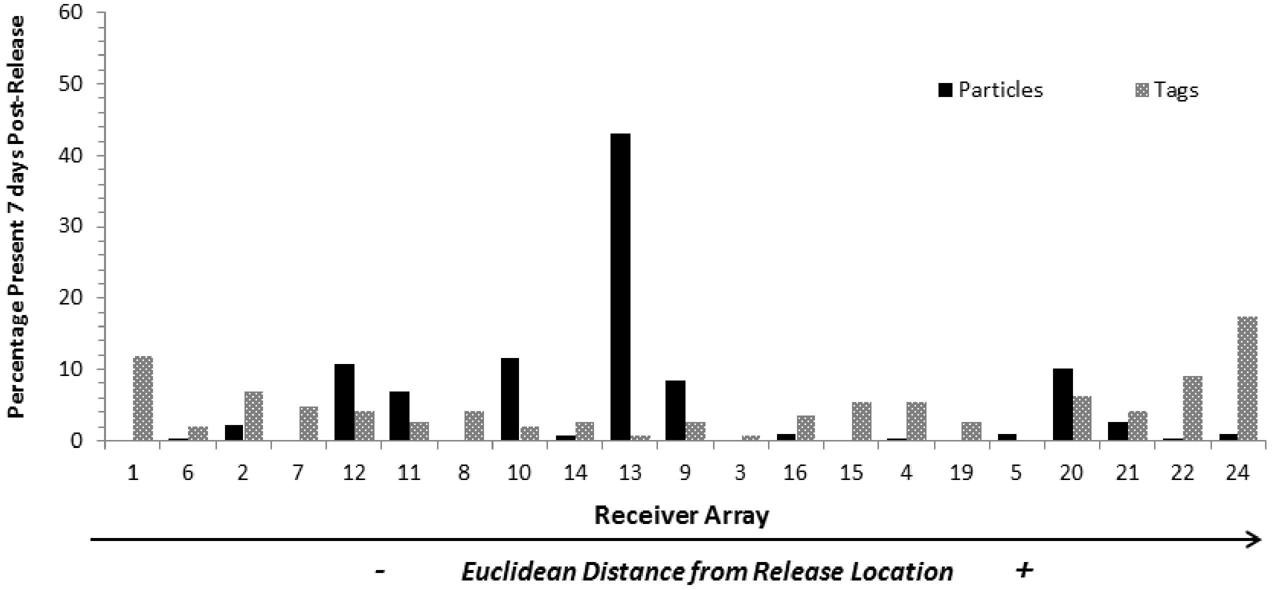


Figure 4-8 **The percentage of steelhead tags and simulated particles present at the arrays on the seventh day after release.** Arrays are ordered from shortest Euclidean distance (left) to greatest (right) Euclidean distance (km) from the release site of Buckley Cove.

Steelhead tags moved much faster than simulated neutrally bouyant particles. This appears to show evidence that steelhead tags either selectively moved with the tides or exhibited constant directed movement while moving through the Delta to travel faster than the water. The next hypothesis (Section 4.1.7) specifically examined if steelhead tags exhibited STST behaviors.

Because we could not determine the exact release time of particles, we assumed that all particles were released on the second day of a release period. Therefore, distances traveled by particles were likely overestimated because particles released on the first day of a release group traveled for longer than 3 days before the distance measurement was calculated. However, because we found that steelhead tags traveled farther than particles, this bias did not affect the outcome of this analysis.

In additon to differences in speed between particles and steelhead tags, the final locations of particles and steelhead tags were very different 7 days following release. Nearly all particles (91%) ended up at one of six arrays in the interior Delta (arrays 12, 11, 10, 13, 9, 20) 7 days following release. Conversly, the final locations of steelhead tags after 7 days were spread out across 20 of 21 arrays, with single-digit percentages occuring at 19 of the 21 arrays. Also, a much higher percentage of steelhead tags (17.4%) were ultimately detected at Chipps Island versus particles (1%). These results show evidence that the PTM inaccurately predicts the final location of steelhead, as well as their speed.

4.1.7 SELECTIVE TIDAL-STREAM TRANSPORT

Whether the migration of juvenile salmonids is passive, partly active, or active has been debated for decades (Martin et al. 2009 and references therein). Because acoustically tagged steelhead tags moved significantly faster than passive particles (see Section 4.1.6), this could indicate that steelhead are undergoing active migration (i.e., swimming downstream irrespective of tidal conditions) or selectively moving with the tides. These fish may exhibit behaviors that allow them to move faster than they would if they were simply passive particles drifting with the water and the processes that control the flow of water, such as tides. Anadromous fish are known to use STST, including salmonids (Moore et al. 1995, Martin et al. 2009). STST behaviors are those where fish actively move into high and low/no flow conditions to facilitate movement up- or downstream. Clements et al. (2012) hypothesized that salmonid smolts move into low-velocity areas during flood tides and into the highest velocity areas during the ebb tides.

The interpretation of results from DSM2 Hydro PTM for management purpose commonly assumes that acoustically tagged salmonids move in a similar manner to passive particles driven purely by hydrodynamics. While this assumption is commonly used for modeling the movement of aquatic species, even in peer-reviewed literature (e.g., Kimmerer and Nobriga 2008), this assumption was probably not accurate for most species including juvenile steelhead (see Section 4.1.6). In particular, salmonids have a complex set of behaviors in response to both biotic (e.g., predators) and abiotic factors (e.g., temperature, salinity, tides). For example, juvenile steelhead that want to reach the ocean as quickly as possible could achieve this by moving into fast-flowing surface waters during ebb tides and moving to lower velocity flows on the flood tides by moving to the sides of the water body or moving to deeper waters (Clements et al. 2012). Moore et al. (1995) found that Atlantic salmon (*Salmo salar*) smolts exhibited a nocturnal, selective ebb tide transport pattern of migration. Therefore, in this analysis, we examined if acoustically tagged juvenile steelhead used STST, and in the next analysis we examined if they migrate more nocturnally or diurnally.

Hypothesis 4.1.7: Steelhead tags did not move using STST.

METHODS FOR TESTING HYPOTHESIS 4.1.7

Following the suggested methods in Appendix 2.2 of the 2012 IRP LOO Annual Review (Kneib et al. 2012), we attempted to estimate φ, which is the contribution of STST behavior to migration (Anderson et al. 2005). Whether a steelhead tag is exhibiting STST behavior or active directed swimming is determined by the value of φ. This value is generated by subtracting the mean particle velocity from the mean velocity of tags, and this product is divided by the root-mean-square (RMS) tidal velocity. If this value, φ, is greater than 0.5, then it is evidence of active directed swimming in the seaward direction. If *φ* is 0.5, smolts are effectively hiding in zero-velocity areas during the entire flood tide and drift downstream during the ebb tide. If *φ* is less than 0.5, this indicates that tidal selective movement occurs during only part of the flood tide and/or that the smolts move into low velocity, but not zero-velocity, areas on the flood tide. A *φ* of 0 indicates passive drift of smolts.

We calculated the mean velocity of particles as predicted by the DSM2 PTM model and steelhead tags between arrays 1 and 7 (Figure 2-3) for the tags detected at both arrays in that order. We calculated *φ* with the following equation: (*U*-*V*) / (*RMS tidal velocity*). *U* is the mean velocity of steelhead tags estimated between arrays 1 and 7, and *V* is the mean velocity of particles that was estimated by conducting the following steps:

- In each of the three PTM runs, 10,000 particles were released from node 25 (array 1) at 1:30 am on the second day of the fish release periods (April 16, May 2, and May 16, 2012).
- We identified the particle flux at node 143 (array 7) at the end of each model run and identified how long before at least half of this value was predicted for node 143 (array 7) in each model run and then subtracted 15 minutes from this number to get an estimate of mean travel time for particles. Because it is unclear when during the time interval that half the particles passed node 143, we chose to err on the side of overestimating mean particle velocity by assuming that they arrived at the beginning of the last 15-minute interval (by subtracting 15 minutes).
- We calculated this value from each of the three new PTM runs that corresponded to the study periods of the three release groups and averaged these three values to estimate the mean travel time of particles. Then, to estimate the mean velocity of particles, we divided 5,660 m by the mean travel time.

To calculate the RMS tidal velocity, we gathered data from the Turner Cut CDEC station (CDEC 2013). The average RMS tidal velocity across the three release groups was calculated for the 5 days after the release of fish (3:00 pm on the day that releases began until 2:45 pm on the fifth day after).

RESULTS FOR HYPOTHESIS 4.1.7

Steelhead tags seemed to exhibit limited STST behavior (*φ*=0.39), as shown in Table 4-7. This suggests that at least in one reach of the Delta, steelhead were exhibiting STST behavior, with selective movement only occurring during part of the flood tide and/or that the steelhead tags move into low velocity, but not zero-velocity areas on the flood tide.

Table 4-7 The mean velocity of particles, mean velocity of steelhead tags, and root-mean-square tidal velocity, and *φ*, which is the contribution of STST behavior to migration.

	Estimates
Mean velocity of particles (m/sec):	0.02
Mean velocity of tags (m/sec):	0.07
RMS tidal velocity (m/sec):	0.13
φ:	0.39

This result further illustrates that steelhead tags should not be treated as passive particles when estimating their migration rate. By not accounting for these specific fish behaviors in the movement rules of simulated particles, physically based models cannot predict the movement of this species. There is growing support for no longer having models treat species as passive particles (Metaxas and Saunders 2009, Delaney et al. 2012). We recommend that models used for predicting smolt movement incorporate important behaviors in response to environmental conditions and be validated using biotelemetry data.

This analysis was conducted to address the concern raised in the 2012 IRP LOO Annual Review to include tidal information to better understand the movement patterns of steelhead tags. However, because this analysis required a confined reach of the Delta (to better ensure steelhead tag routing) paired with locally measured hydrodynamic data, we were limited to examining a single reach. Therefore, this analysis was exploratory in nature, and we suggest that future studies (including deployment of tidal velocity monitoring stations necessary to collect site-specific data) be conducted to quantify this behavior on a larger scale in various parts of the Delta.

4.1.8 DIURNAL MOVEMENT PATTERNS

Another behavior that could be important in understanding the migration, routing, and survival of steelhead is whether steelhead are migrating more during the day or night. Because migrating steelhead are vulnerable to visual ambush predators, such as striped bass (*Morone saxatilis),* it may be beneficial for steelhead to migrate during the nighttime to reduce their chance of being preyed upon. However, the limited studies of activity patterns of steelhead show that they are more active during the day (Bégout Anras and Lagardère 2004, Chapman et al. 2013).

Hypothesis 4.1.8: The movement of steelhead tags in the San Joaquin River and interior Delta was not related to day/night.

METHODS FOR TESTING HYPOTHESIS 4.1.8

The timing of when steelhead tags are first detected at arrays 4 (San Joaquin River) and 9 (interior Delta) was examined for a day/night effect. Two-tail binomial tests were conducted to determine if significantly more steelhead tags were first detected during the day (i.e., 06:00:01–18:00:00) than during the night (i.e., 18:00:01–06:00:00). This exploratory analysis allowed us to examine if there was any evidence that tags were moving more during the day or night. We assumed that if steelhead tags were migrating more during the day, then a significantly greater proportion of tags would be first detected during the daytime. Similarly, we assumed that if steelhead tags were migrating more during the night, then a significantly greater of proportions of tags would be first detected during the nighttime.

RESULTS FOR HYPOTHESIS 4.1.8

We found that 46.7% and 62.8% of steelhead tags were first detected during the day (06:00:01–18:00:00) at arrays 4 and 9, respectively. Given the different results found between the two arrays, we analyzed all 23 arrays where Stipulation Study steelhead tags were detected and analyzed for this hypothesis (Table 4-8). Array 18 did not detect any steelhead tags deployed for the Stipulation Study and therefore was not examined in the analysis. When we examined all the arrays, only 34.8% of the arrays had more tags detected during the day than during the night (Table 4-8).

There seems to be a spatial pattern in significant results for steelhead tags released for the Stipulation Study (Figure 4-9). At many of the arrays (arrays 2, 3, 11, 22, and 24) along the San Joaquin River, significantly ($P<0.05$) more Stipulation Study steelhead tags were first detected during the night. Conversely, some arrays (arrays 8, 9, 10, and 12) in the southeast section of the study area had significantly ($P<0.05$) more tags first detected during the day. Arrays 7 and 20, also in the southeast section of the study area, had marginally significantly (i.e., $0.05\geq P\leq 0.10$) more steelhead tags first detected during the day.

There is some evidence for a spatial pattern in diurnal steelhead tag movements. However, the mechanism for this pattern is unknown and should be further examined in future studies. A potential bias in diurnal timing data is the possible ingestion of steelhead tags by predators. The spatial pattern observed in diurnal movements may be due to spatial patterns in predation. For example, if more predation is occurring in the interior Delta versus the Mainstem, the diurnal patterns in movement may be the result of differences in predator versus steelhead movement behavior. However, this relationship is purely speculative, and future studies specifically designed to examine diurnal movement behavior should be conducted to understand the underlying mechanism.

Table 4-8 For each array, the number of Stipulation Study steelhead tags that were first detected during the daytime and nighttime, the total number of tags detected, the proportion of tags first detected during the daytime and nighttime, and the two-tail P-value from the binomial test to see if more tags were detected during the day or night.

Array	Tags first detected between 06:01-18:00	Tags first detected between 18:01-06:00	Total number of tags	Percent first detected during the day	Percent first detected during the night	P-value
1	215	220	435	49.4	50.6	0.85
2	109	180	289	37.7	62.3	<0.01
3	51	89	140	36.4	63.6	<0.01
4	70	80	150	46.7	53.3	0.46
5	15	24	39	38.5	61.5	0.20
6	49	67	116	42.2	57.8	0.11
7	94	69	163	57.7	42.3	0.06
8	90	64	154	58.4	41.6	0.04
9	86	51	137	62.8	37.2	<0.01
10	25	4	29	86.2	13.8	<0.01
11	25	57	82	30.5	69.5	<0.01
12	49	27	76	64.5	35.5	0.02
13	39	50	89	43.8	56.2	0.29
14	24	20	44	54.5	45.5	0.65
15	12	16	28	42.9	57.1	0.57
16	32	33	65	49.2	50.8	1.00
17	4	9	13	30.8	69.2	0.27
19	32	26	58	55.2	44.8	0.51
20	20	10	30	66.7	33.3	0.10
21	13	21	34	38.2	61.8	0.23
22	49	81	130	37.7	62.3	0.01
23	0	2	2	0.0	100.0	0.50
24	30	83	113	26.5	73.5	<0.01

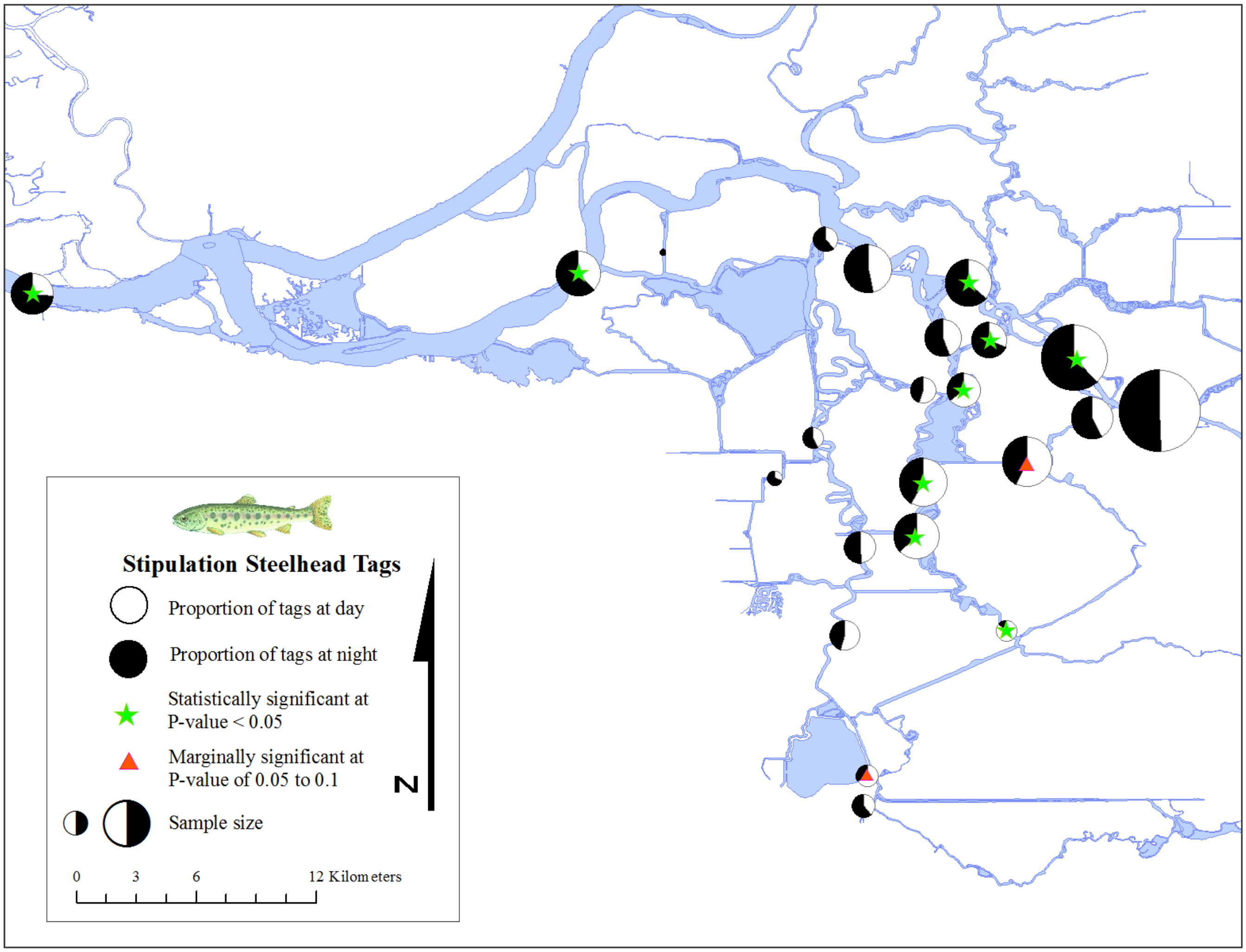


Figure 4-9 The proportion of steelhead tags deployed for the 2012 Stipulation Study first detected during the day or night. The size of the pie chart is scaled to the number of tags detected at each of the arrays. The white portion of the pie chart is the percent of tags detected during the day (i.e., 06:00:01–18:00:00), and the black portion is the percent of tags detected during the night (i.e., 18:00:01-06:00:00). The green star indicates the result for that array is significant as determined by the two-tail P-value from the binomial test. The red triangle indicates the result for that array is marginally significant as determined by the two-tail P-values from the binomial tests.

4.2 ROUTE-LEVEL ANALYSES

In this section, we examine how steelhead tags moved and survived through the Delta using different defined routes. We built a multistate statistical release-recapture model to estimate receiver detection probabilities, route entrainment probabilities, transition probabilities, and survival probabilities. In analyses not using the model we estimated if travel times of steelhead tags were affected by the different OMR flow conditions examined in this study.

4.2.1 ROUTE-SPECIFIC TRANSITION PROBABILITIES

To properly manage a species and promote its survival through the Delta, we hypothesize that we need to know if the survival of a species varies between different routes. Also, we hypothesize that certain OMR flows may foster more favorable conditions for the survival of the species. If the survival of steelhead varies between routes and/or release groups, we can try to re-create conditions or promote the use of specific routes through specific OMR flows that will result in increased steelhead survival.

Hypothesis 4.2.1: Route-specific transition probabilities of steelhead tags were not significantly related to the route taken and/or release group.

METHODS FOR TESTING HYPOTHESIS 4.2.1

To estimate detection probabilities, route entrainment, survival, and transition probabilities, we built a multistate statistical release-recapture model in the program USER (Lady et al. 2008), which is similar to those developed by Perry et al. (2010), SJRGA (2011, 2013), and Buchanan et al. (2013). For the Stipulation Study model, we used all steelhead tags that were detected at array 1 (Figure 2-3). Last detection data were used in the model, as was done in previous modeling efforts (e.g., Buchanan et al. 2013).

Originally, we intended to include release group as a covariate in the model to examine how survival and routing differed between release groups or OMR flow levels (Groups 1 and 2 versus Group 3). However, during the model fitting process, USER failed to converge on individual release group models and only converged and provided parameter estimates and standard errors for the pooled data from all release groups. Therefore, the following methods and results reflect a model that combined all data across release groups (i.e., release group were not included as a covariate).

Acoustic receiver coverage and detection data informed the delineation of fish routes from approximately Stockton to Chipps Island (including through the interior Delta and south Delta salvage facilities). In the analysis, we examined six primary fish routes to estimate route-specific transition probabilities. Route-specific transition probability is a measure of the number of steelhead tags that went through a route and survived. Therefore, the complement of route-specific transition probability is not just mortality but is mortality, using a different route, or not reaching Chipps Island in 15 days. However, 94% of the steelhead tags that reached Chipps Island did so in the 15 days after their release, therefore the complement of route-specific transition probability is mainly mortality and the probability of using a different route. The following are the six defined routes (for points of reference listed below, refer to Figure 1-1):

- Turner Cut to Chipps Island area (Figure 4-10).
- Route to Chipps Island area without using Turner Cut (Figure 4-11).
- Turner Cut to Chipps Island area via SWP (Figure 4-12).
- Route to Chipps Island area via SWP without using Turner Cut (Figure 4-13).
- Turner Cut to Chipps Island area via CVP (Figure 4-14).
- Route to Chipps Island area via CVP without using Turner Cut (Figure 4-15).

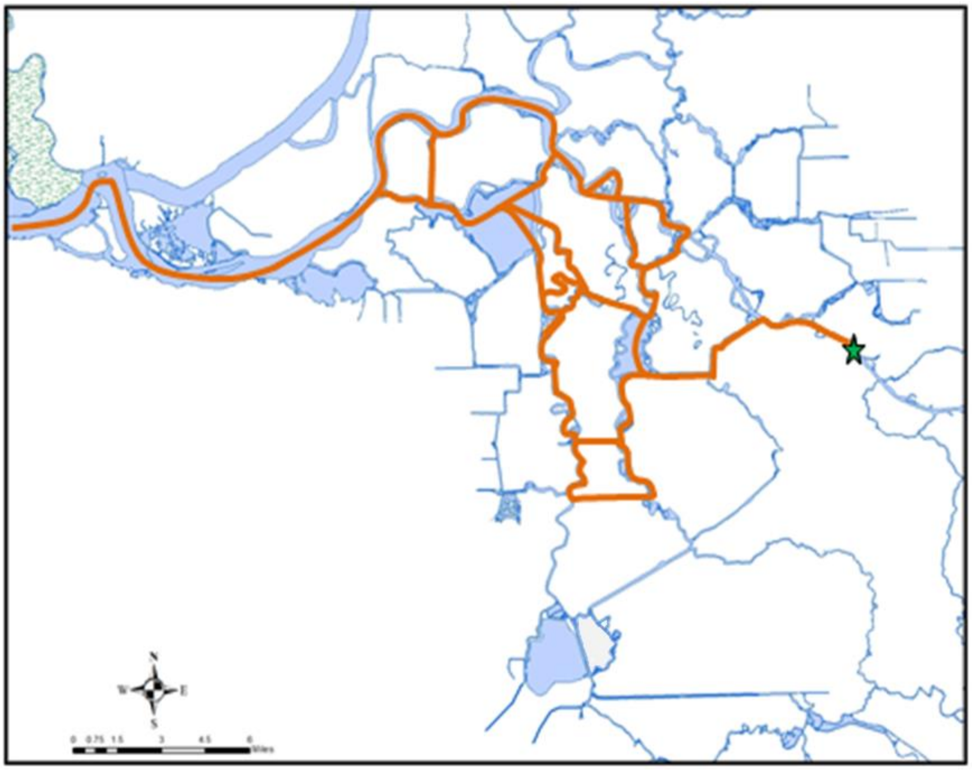


Figure 4-10 Turner Cut to Chipps Island area route.

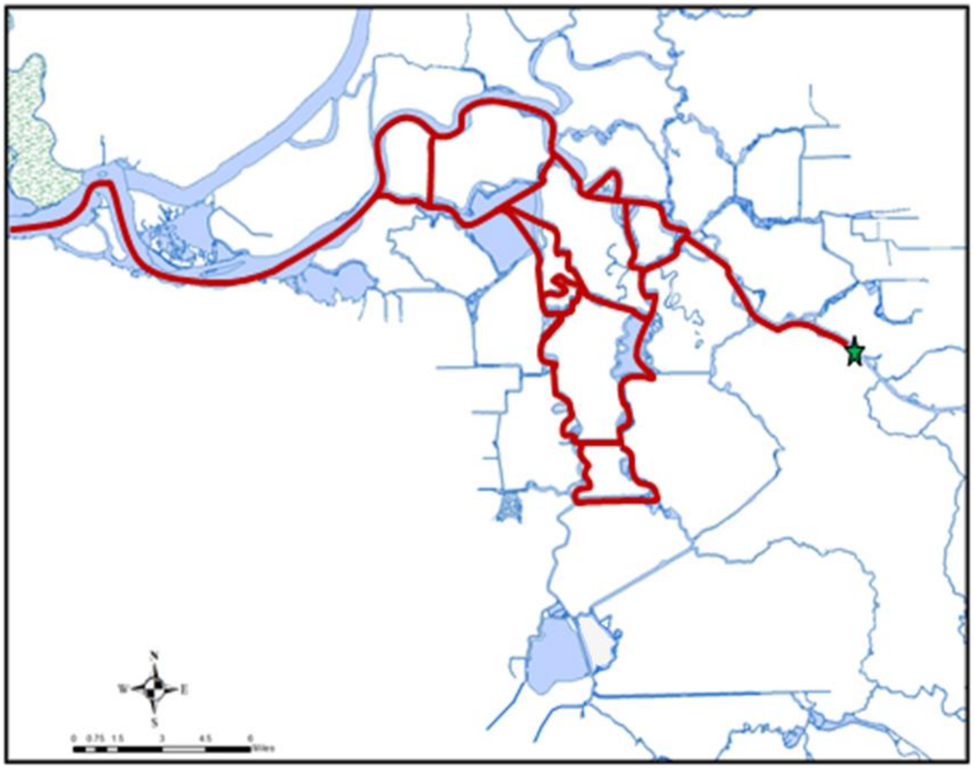


Figure 4-11 Route to Chipps Island area without using Turner Cut.

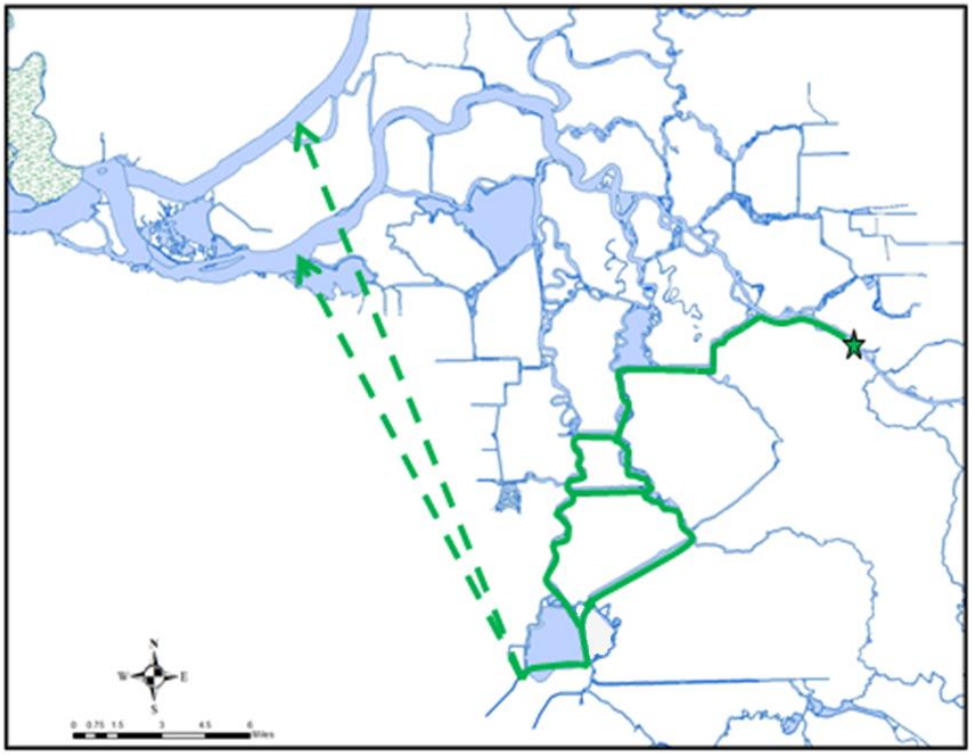


Figure 4-12 **Route using Turner Cut to Chipps Island area via SWP**. Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

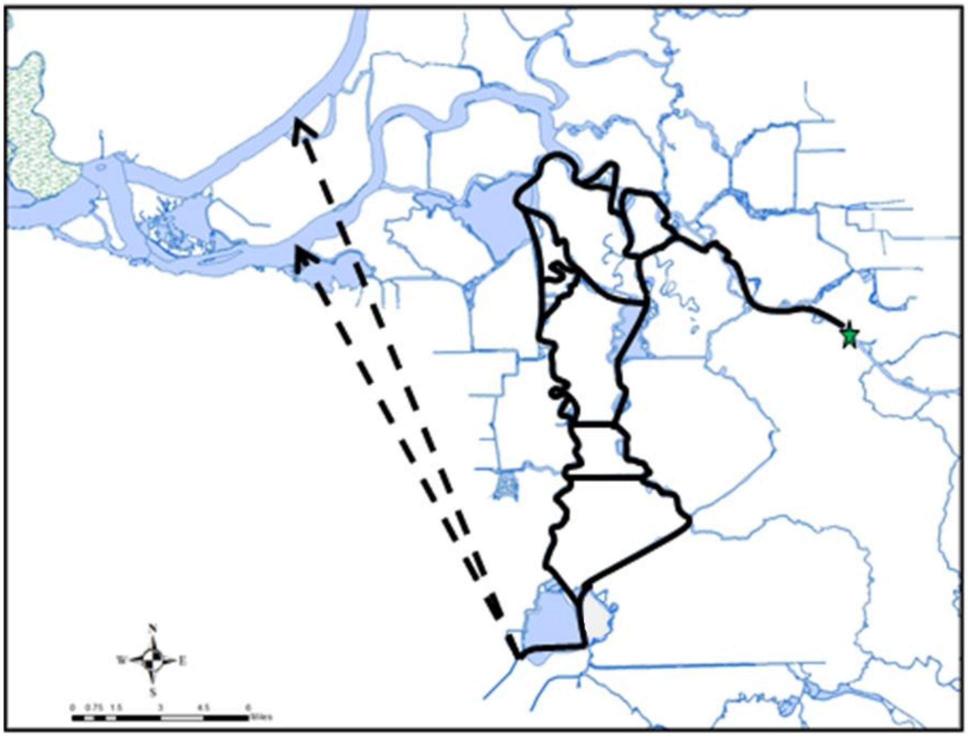


Figure 4-13 **Route to Chipps Island area via SWP without using Turner Cut**. Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

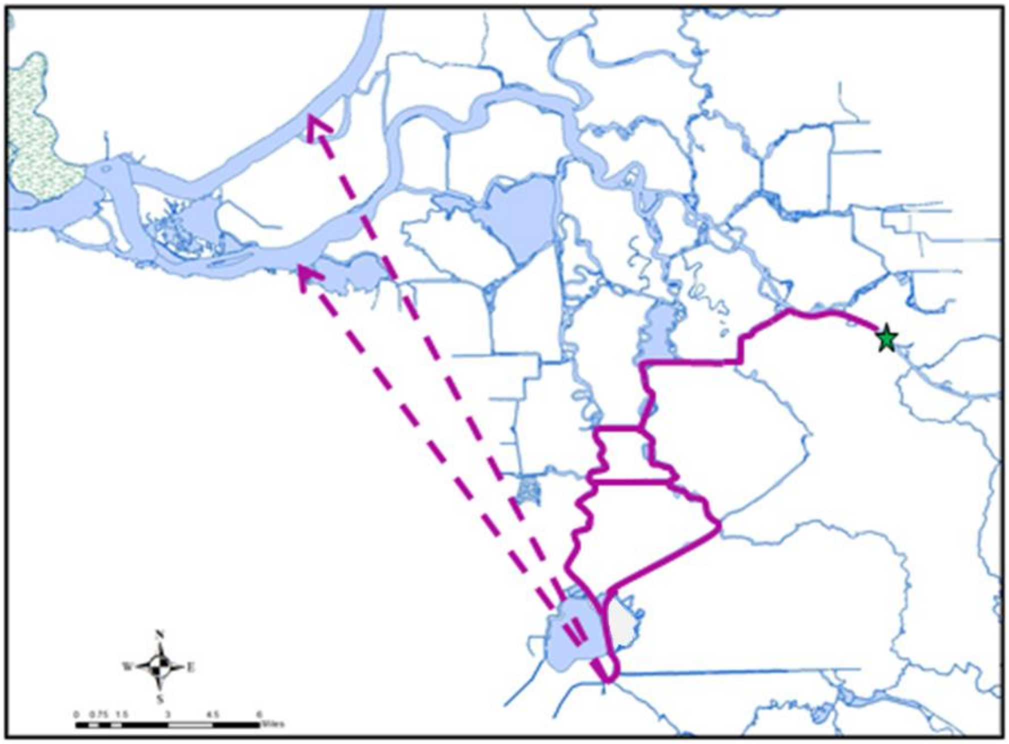


Figure 4-14 **Route using Turner Cut to Chipps Island area via CVP**. Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

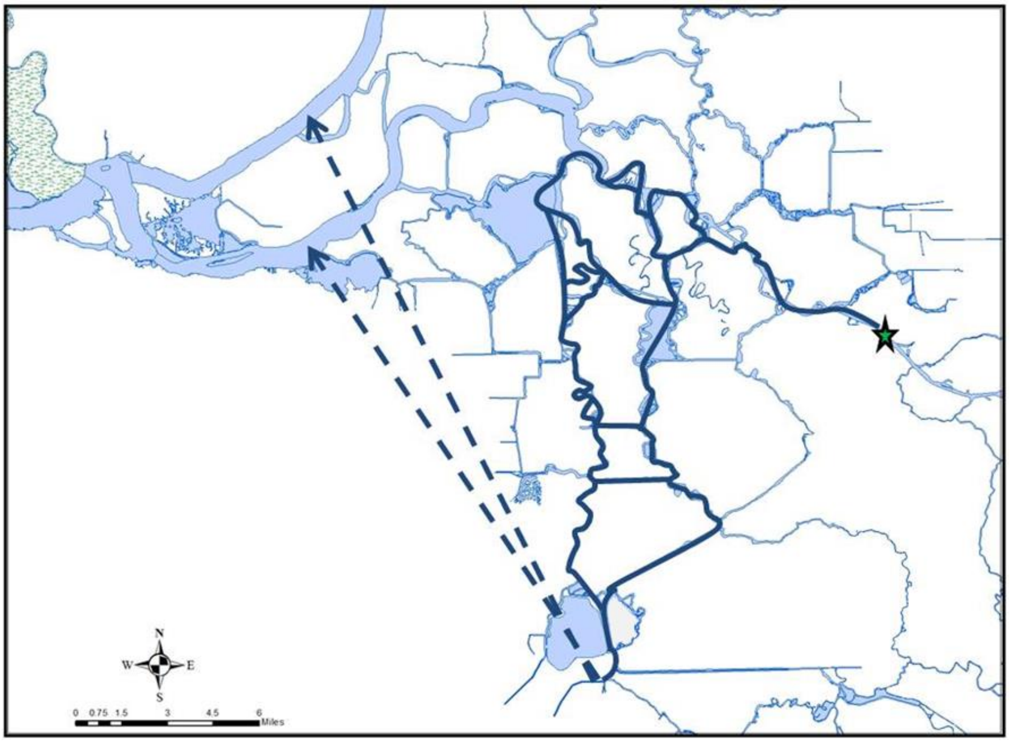


Figure 4-15 **Route to Chipps Island area via CVP without using Turner Cut**. Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

These routes (Figure 4-10 to Figure 4-15) were the basis for selecting a subset of arrays from the arrays deployed for the Stipulation Study and Six-Year Study in the study area (Figure 2-3). Because of the complexity of Delta channels and the lack of a priori consideration of the placement of receiver arrays to test specific routing and survival hypotheses, we eliminated receiver arrays from the analysis that did not allow a calculation of unique route entrainment or reach survival probabilities. For example, incomplete receiver coverage at the San Joaquin River junctions downstream of Turner Cut and in the myriad of channel bifurcations in the interior Delta limited our ability to calculate route entrainment and survival probabilities in these areas. Based on these considerations, the locations of arrays that we used in the model are shown in Figure 4-16, and the locations of each array's individual receivers are described in Table 4-9. Using these arrays, we generated the model schematic shown in Figure 4-17. In the model, we only used steelhead tags that were initially detected at array 1 to remove the expression of handling mortality. This schematic (Figure 4-17) incorporates the six routes, but allowed us to derive a model that balances complexity with clarity.

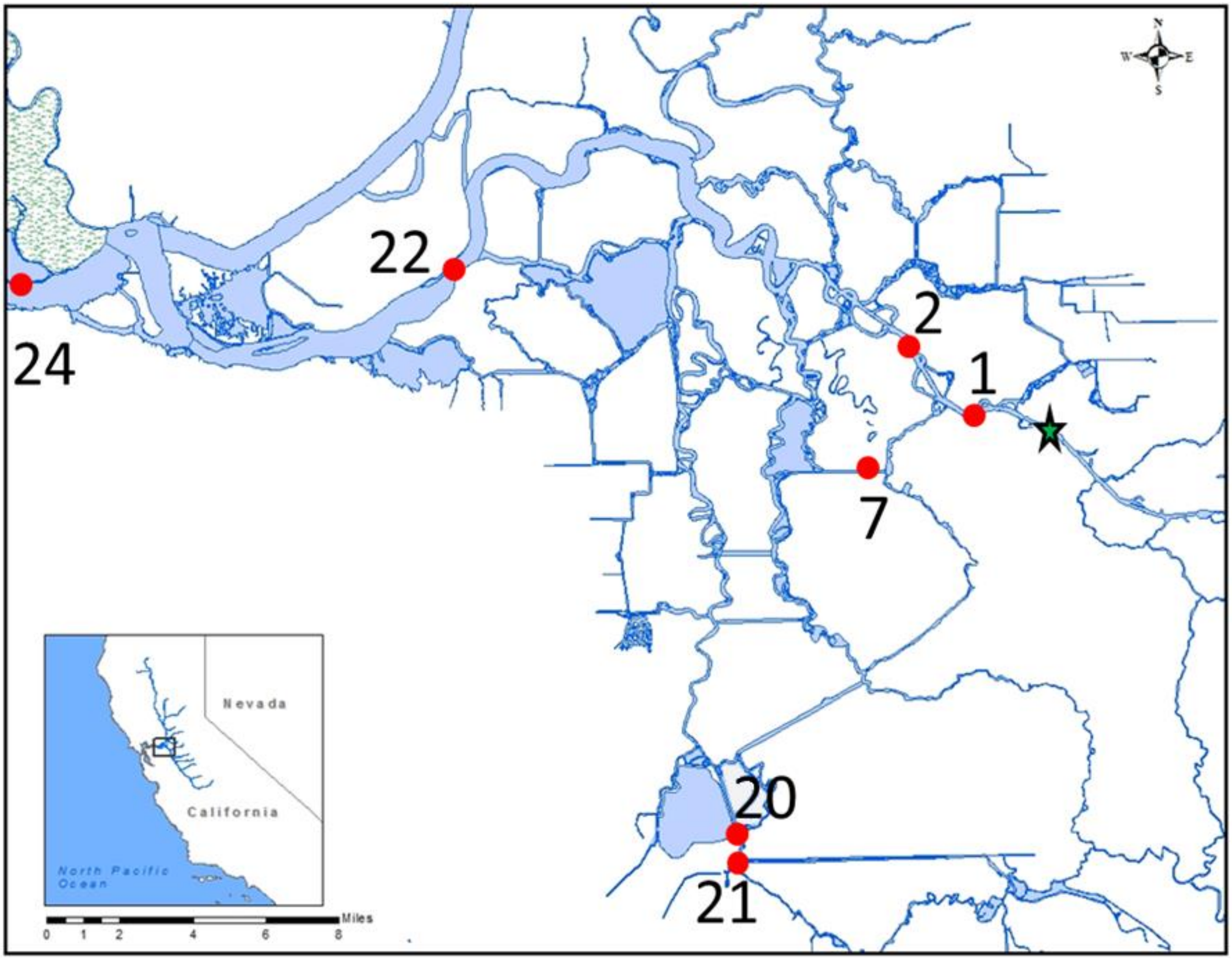


Figure 4-16 The location of acoustic telemetry arrays that were included in the schematic of the multistate statistical model described in Figure 4-17 to estimate route entrainment, survival, detection, and transition probabilities. The green star is where the acoustically tagged steelhead were released for the 2012 Stipulation Study.

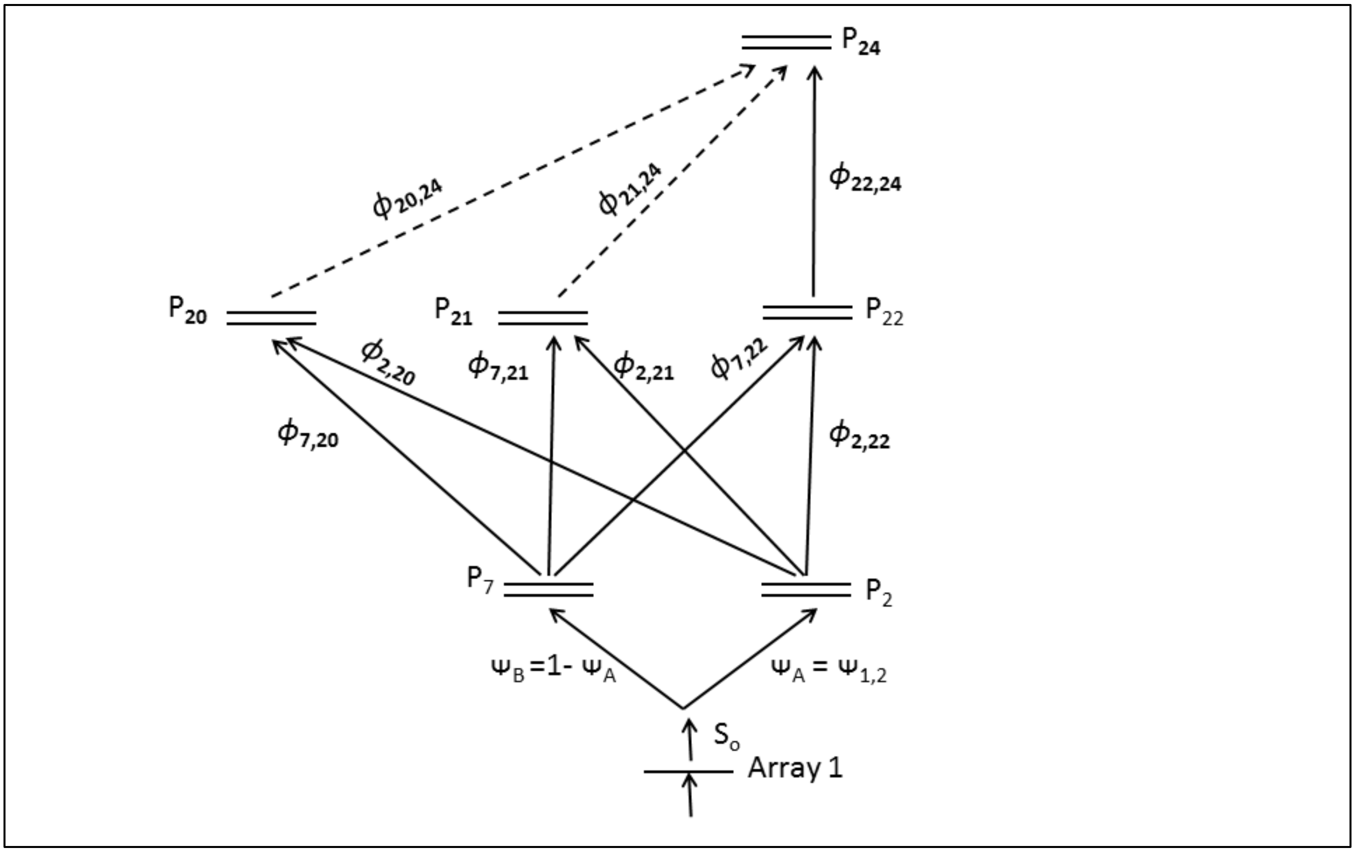


Figure 4-17 **Schematic of the multistate statistical model.** Estimated parameters are the probabilities of survival (S), route entrainment (ψ), transition (ϕ), and detection (P). Single arrays are denoted with a single line where dual rays are shown as double lines. Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

Table 4-9 Array number, receiver location upstream or downstream, receiver code, station name, and latitude/longitude (decimal degrees). *Only has one location point available as receivers were deployed very close to each other in a station (e.g., station name "JPE.1a/b" for receivers 300915 and 300916). Data from KMZ (version 19) provided to us by Dr. Josh Israel.

Array	Upstream (A) or Downstream (B)	Receiver Code	Station Name	Latitude	Longitude
1	A	300995	9B	37.9950	-121.4381
1	A	300998	9A	37.9949	-121.4404
2	A	300899	MACU.1	38.0175	-121.4634
2	A	300900	MACD.1	38.0234	-121.4667
2	B	300901	MACU.2	38.0184	-121.4620
2	B	300902	MACD.2	38.0246	-121.4651
7	A	301004	5B	37.9719	-121.4846
7	B	300999	5A	37.9711	-121.4862
20	A	300888	RGU1	37.8301	-121.5566
20	A	300889	RGU2	37.8297	-121.5569
20	B	460009	RGD2-HRR	37.8304	-121.5572
20	B	460010	RGD2-HRR	37.8299	-121.5576
20	B	460011	RGD1-HRR	37.8299	-121.5576
21	A	460012	CVPU-HRR	37.8170	-121.5583
21	A	300895	CVPD	37.8167	-121.5589
21	B	300896	CVPT	37.8158	-121.5591
22	A	300915	JPE.1a*	38.0569*	-121.6850*
22	A	300916	JPE.1b*	38.0569*	-121.6850*
22	A	300917	JPE.2a*	38.0576*	-121.6861*
22	A	300918	JPE.2b*	38.0576*	-121.6861*
22	A	300919	JPE.3a*	38.0561*	-121.6842*
22	A	300920	JPE.3b*	38.0561*	-121.6842*
22	A	300921	JPE.4a*	38.0581*	-121.6873*
22	A	300922	JPE.4b*	38.0581*	-121.6873*
22	B	300923	JPW.1a*	38.0553*	-121.6876*
22	B	300924	JPW.1b*	38.0553*	-121.6876*
22	B	300925	JPW.2a*	38.0560*	-121.6885*
22	B	300926	JPW.2b*	38.0560*	-121.6885*
22	B	300927	JPW.3a*	38.0544*	-121.6870*
22	B	300928	JPW.3b*	38.0544*	-121.6870*
22	B	300929	JPW.4a*	38.0564*	-121.6896*
22	B	300930	JPW.4b*	38.0564*	-121.6896*

Table 4-9 Array number, receiver location upstream or downstream, receiver code, station name, and latitude/longitude (decimal degrees). *Only has one location point available as receivers were deployed very close to each other in a station (e.g., station name "JPE.1a/b" for receivers 300915 and 300916). Data from KMZ (version 19) provided to us by Dr. Josh Israel.

Array	Upstream (A) or Downstream (B)	Receiver Code	Station Name	Latitude	Longitude
24	A	300931	MAE.1a*	38.0474*	-121.9320*
24	A	300932	MAE.1b*	38.0474*	-121.9320*
24	A	300933	MAE.2a*	38.0489*	-121.9304*
24	A	300934	MAE.2b*	38.0489*	-121.9304*
24	A	300935	MAE.3a*	38.0468*	-121.9324*
24	A	300936	MAE.3b*	38.0468*	-121.9324*
24	A	300937	MAE.4a*	38.0507*	-121.9309*
24	A	300938	MAE.4b*	38.0507*	-121.9309*
24	A	300939	MAE.5a*	38.0458*	-121.9328*
24	A	300940	MAE.5b*	38.0458*	-121.9328*
24	A	300941	MAE.6a*	38.0513*	-121.9306*
24	A	300942	MAE.6b*	38.0513*	-121.9306*
24	B	300943	MAW.1a*	38.0480*	-121.9332*
24	B	300979	MAW.1b*	38.0480*	-121.9332*
24	B	300980	MAW.2a*	38.0499*	-121.9331*
24	B	300981	MAW.2b*	38.0499*	-121.9331*
24	B	300982	MAW.3a*	38.0474*	-121.9338*
24	B	300983	MAW.3b*	38.0474*	-121.9338*
24	B	300985	MAW.4a*	38.0518*	-121.9341*
24	B	300986	MAW.4b*	38.0518*	-121.9341*
24	B	300987	MAW.5a*	38.0467*	-121.9352*
24	B	300988	MAW.5b*	38.0467*	-121.9352*
24	B	300989	MAW.6a*	38.0523*	-121.9337*
24	B	300990	MAW.6b*	38.0523*	-121.9337*

In addition to estimating these six route-specific transition probabilities, we also estimated two route-specific survival probabilities (Mainstem and Turner Cut route), route entrainment probability at Turner Cut, and overall Delta survival (see Section 4.2.2 for entrainment and survival results). The equations for each of the transition probability, entrainment, and survival calculations are shown in Table 4-10.

To estimate parameters, we used seed values of 0.1 in a Fletch Quasi-Newton optimizer and an alpha level of 0.05. We used the default settings for the Fletch Quasi-Newton optimizer, which are a maximum of 200 iterations, with a precision of 1e-06, and a proportional step size of 1e-06. For a steelhead tag to be included in the analyses for the model, it needed to be detected at array 1 (Figure 4-17). If a steelhead tag were detected at more than one array on the same level of the schematic (e.g., arrays 7 and 2; Figure 4-17), the tag was considered to have only been detected by the array on that level of the schematic that last detected the tag. The only exception to this rule was that if a steelhead tag were detected at an export facility and array 22 (Jersey Point), it was considered to be detected at the export facility where it was last detected. For example, if a tag was detected at array 21 then 22 then 24, in the model it would be considered to have been detected at array 21 and then next at array 24. We feel this assumption is valid because otherwise tags that went through salvage and were later detected at array 22 before reaching array 24 (Chipps Island) would not be identified as a "salvaged" steelhead tag because these arrays are on the same level in the model. This would be misleading.

Table 4-10 The codes and equations for route-specific transition probabilities, Turner Cut route entrainment (into the interior Delta), and survival probabilities. Turner Cut route entrainment was fit by model. Terms that start with "ϕ" denote a transition probability, terms that start with "s" denote a route-specific transition probability, terms that start with "S" denote a route-specific survival probability, s0 is the initial survival, terms that start with "Ψ" denote a route entrainment probability and is the parameter that is estimated by the model. The number and letter following one of these terms in the equation are from the array to the next array. For example, ϕ2,22 is the transition probability from 2 to 22 and ϕ2,21 is the transition probability from 2 to 21.

Description of the route	Code	Equation
Turner Cut to Chipps Island area (route-specific transition probability)	sA	ϕ ,22 * ϕ22,24
Route to Chipps Island area without using Turner Cut (route-specific transition probability)	sB	ϕ2,22 * ϕ22,24
Turner Cut to Chipps Island area via SWP (route-specific transition probability)	sC	ϕ ,20 * ϕ20,24
Route to Chipps Island area via SWP without using Turner Cut (route-specific transition probability)	sD	ϕ2,20 * ϕ20,24
Turner Cut to Chipps Island area via CVP (route-specific transition probability)	sE	ϕ ,21 * ϕ21,24
Route to Chipps Island area via CVP without using Turner Cut (route-specific transition probability)	sF	ϕ2,21 * ϕ21,24
Route to Chipps Island without using Turner Cut (route-specific survival probability)	S2C	ϕ2,22 * ϕ22,24 + ϕ2,20 * ϕ20,24 + ϕ2,21 * ϕ21,24
Route to Chipps Island using Turner Cut (route-specific survival probability)	S7C	ϕ ,22 * ϕ22,24 + ϕ ,20 * ϕ20,24 + ϕ ,21 * ϕ21,24
Turner Cut route entrainment	ΨB=1-ΨA	Fit by model
Overall survival	STotal	s0*(ΨA * sB + ΨA * sD + ΨA * sF + ΨB * sA + ΨB * sC + ΨB * sE)

Many assumptions are made when fitting a multistate statistical release-recapture model for estimating survival and routing in a branching system. The following are the modeling assumptions adapted from the presentation "*Survival Analysis of Tagging Data*" by Drs. R. Buchanan and R. Perry as part of a survival analysis workshop, June 28–29, 2011 (Buchanan and Perry 2011):

1. No tag failure or tag loss.
2. Every fish has equal and independent probability of success.
3. Every fish has equal and independent probability of detection, given it survives to the detection location.
4. Upstream detection history has no effect on downstream survival and detection.
5. Tagging has no effect on survival.
6. Detection is instantaneous.

7. Tags are read correctly.
8. Tagged sample is representative of the population.
9. All detections come from live study fish.
10. All mortality occurs first; then transition occurs.
11. Equal survival from the junction to each of the downstream arrays.

We assumed that these assumptions were met, but as occurs in any model, these assumptions could be violated. Also, given the complexity of the study system and the long list of stringent assumptions of the model, collecting data, and designing a model where all assumptions were met was challenging. Further, attempting to meet one assumption can sometimes cause a violation of another assumption of the model. For this reason, the effect of each modeling decision needed to be weighed upon all the assumptions to determine what form of the model was best. In the following paragraphs, we describe key modeling decisions that were made to best meet several key assumptions that were vital to our goal of estimating a route entrainment probability at Turner Cut.

In the model, we wanted to estimate route entrainment probabilities for steelhead tags that continued traveling along the Mainstem San Joaquin River and those entering Turner Cut. To estimate these routes without bias, all assumptions of the model should be met. We originally proposed to use arrays 2 and 6 (Figure 2-3) at the Turner Cut junction in the model since we wanted to use arrays immediately downstream of Turner Cut to avoid violating the assumption that all mortality occurs first and then transition occurs.

However, during exploration of the model input data, we estimated release group-specific detection probabilities for dual receiver arrays at this junction to examine if detection probabilities were constant across release groups, therefore meeting the assumption of equal and independent detection probability. The Manly and Parr (1968) method was applied to estimate detection probabilities at each dual array. The Manly and Parr method requires dual arrays and is based on the assumption that tags passing an array are detected by one or more of the receivers of the arrays. If this assumption is not met, then the detection probability for that array will be overestimated because tags not detected by any receiver are not counted in the estimation of the detection probability. All arrays that we considered using for the Turner Cut junction (arrays 2, 6, and 7) were dual arrays. Probability of detection was estimated at the array-level using these equations:

$$\hat{p}_1 = \frac{AB}{AB + B0}, \; \hat{p}_2 = \frac{AB}{A0 + AB}, \text{ and } \hat{P} = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2);$$

where p_1 is the detection probability of the upstream receiver(s), *AB* is the number of fish detected at both upstream and downstream receiver(s), *B0* is the number of fish detected at the downstream receiver(s) only, *A0* is the number of fish detected at the upstream receiver(s) only, p_2 is the detection probability of the downstream receiver(s), and p is the overall detection probability of the array.

Unlike at receiver arrays 2 and 7 (Table 4-11), the probability of detection varied with release group at array 6 (Table 4-12). For array 6, Release Group 3 had a high detection probability (100%), while the detection probabilities of Release Groups 1 and 2 were much lower, with estimates of 47% and 83%, respectively. These results justified the use of array 7 instead of array 6 in the multistate model, as the model that incorporated array 6 violated the assumption that every steelhead tag has an equal and independent probability of detection.

Table 4-11 The estimated detection probabilities p) for arrays 2 and 7, for the model that included array 7 instead of 6, for Release Groups 1, 2, and 3. p1 is the detection probability of the upstream receiver(s), p2 is the detection probability of the downstream receiver(s), and p is the overall detection probability for the array. All detection probabilities are expressed as percentages.

Array 2			
Release Group	**1**	**2**	**3**
p_1	100	99	100
p_2	97	96	93
p	100	100	100

Array 7			
Release Group	**1**	**2**	**3**
p_1	100	98	100
p_2	98	100	100
p	100	100	100

Table 4-12 The estimated detection probabilities (p) for arrays 2 and 6, for the model that included array 6 instead of 7, for Release Groups 1, 2, and 3. p1 is the detection probability of the upstream receiver(s), p2 is the detection probability of the downstream receiver(s), and p is the overall detection probability for the array. All detection probabilities are expressed as percentages.

Array 2			
Release Group	**1**	**2**	**3**
p_1	100	99	100
p_2	93	93	93
p	100	100	100

Array 6			
Release Group	**1**	**2**	**3**
p_1	20	50	100
p_2	33	67	96
p	47	83	100

The detection probability for array 2 varies slightly (<5%) in the two different tables (Table 4-11 and Table 4-12) since the raw data for these tables and the model both use last detection data. Therefore, the exact number of tags last detected at array 2 depends on whether the interior array is array 6 or 7. The receivers making the upstream and downstream lines of the dual arrays 7 and 2 are reported in Table 4-9. The receivers and their locations that are part of array 6 are shown in Table 4-13.

Table 4-13 Receiver details for array 6 including receiver location (upstream or downstream), receiver code, station name, and longitude and latitude (decimal degrees).

Array	Upstream (A) or Downstream (B)	Receiver Code	Station Name	Latitude	Longitude
6	A	300886	TCE	37.9917	-121.4554
6	B	300887	TCW	37.9905	-121.4563

While including array 7 instead of array 6 avoided violation of the equal and independent detection probability assumption, the distances from array 1 (upstream of the junction) to arrays 2 and 7 were different, and therefore there was a risk of violating the assumption of equal survival from the junction to each of the downstream arrays. However, although absolute distance between arrays 1 and 2 might be slightly closer to the distance between arrays 1 and 6 versus 1 and 7, there is great inequality in the distance between array 1 and either pair of downstream receivers. If arrays 2 and 6 were used, the distance between arrays 1 and 2 was more than twice the distance between arrays 1 and 6. If arrays 2 and 7 were used, the distance between array 1 and 7 was almost twice as far as the distance between arrays 1 and 2. Therefore, arguably using either array 6 or 7 could violate the assumption of equal survival.

With array 7 being farther downstream from array 2 than array 6, we wanted to make sure that most steelhead tags arrived at array 7 from the Turner Cut junction and did not reach array 7 from the interior Delta side (possibly entering the interior Delta from Columbia Cut). We examined this assumption and found that less than 5% of steelhead tags did not reach array 7 from Turner Cut, thereby, providing further support for the use of array 7 in the model.

Another concern with using array 7 involves Whiskey Slough, a channel between arrays 6 and 7. If steelhead tags were lost in Whiskey Slough prior to reaching array 7, then route entrainment estimates at Turner Cut would be biased. However, Whiskey Slough is a dead-end and does not connect to the network of Delta channels. And since it is a dead-end and flow does not pass all the way through this slough, we assumed that there is low flow attraction for steelhead tags at the head of Whiskey Slough, thereby limiting movement into the slough.

In conclusion, we decided to run the model with array 7 instead of array 6 because only array 6 clearly violated a model assumption, with detection probability varying with release group. Also, these findings argued for use of array 7 in all additional analyses, which was the way we preceded with the analysis in this report.

RESULTS FOR HYPOTHESIS 4.2.1

The route-specific transition probabilities for the six defined routes are summarized in Table 4-14.

Table 4-14 Route-specific transition probabilities and standard error for the six transition probability routes.

Route to Chipps Island	Route-specific Transition (%)	Standard Error (%)
Via Turner Cut	7.0	1.6
Without using Turner Cut	24.8	2.0
Via Turner Cut and SWP	0.5	0.5
Via SWP without using Turner Cut	0.2	0.2
Via Turner Cut and CVP	19.6	2.8
Via CVP without using Turner Cut	31.7	1.9

The highest transition probability was for the route that did not use Turner Cut and traveled to Chipps Island though salvage operations of CVP. The second highest transition probability was the route that did not use Turner Cut and traveled to Chipps Island without being salvaged. The two lowest transition probabilities were for the two routes to Chipps Island that traveled through Clifton Court Forebay and salvage operations at SWP.

4.2.2 ROUTE-SPECIFIC AND OVERALL SURVIVAL PROBABILITIES

While route-specific transition probabilities were useful, they were harder to interpret than route-specific and overall survival probabilities. While the complement of route-specific transition probability was not just mortality, but was mortality, using a different route or not reaching Chipps Island in 15 days, the complement of overall survival and route-specific survival estimates was mortality and not reaching Chipps Island in 15 days. However, 94% of the steelhead tags that were ever detected at Chipps Island were detected in the 15 days after their release, therefore the complement of survival is mainly mortality. Therefore, we also estimated the overall survival probabilities and route-specific survival probabilities where the data, study design, and the assumptions of the model allowed. These offered invaluable insights on what percent of the steelhead tags successfully migrated through the system and what routes had the greater proportion making it to the end point (i.e., at array 24, the array near Chipps Island [Figure 2-3]).

Hypothesis 4.2.2: The estimated route-specific survival for the Turner Cut route was not significantly different from the Mainstem route.

From the release-recapture model, we could not only estimate the six route-specific transition probabilities (see Section 4.2.1), but we could also estimate route entrainment at Turner Cut, overall Delta survival, and two route-specific survival probabilities:

- Turner Cut Route (Figure 4-18): steelhead tags that were last detected at array 7 if detected at array 2 and/or array 7.
- Mainstem Route (Figure 4-19): steelhead tags that were last detected at array 2 if detected at array 2 and/or array 7.

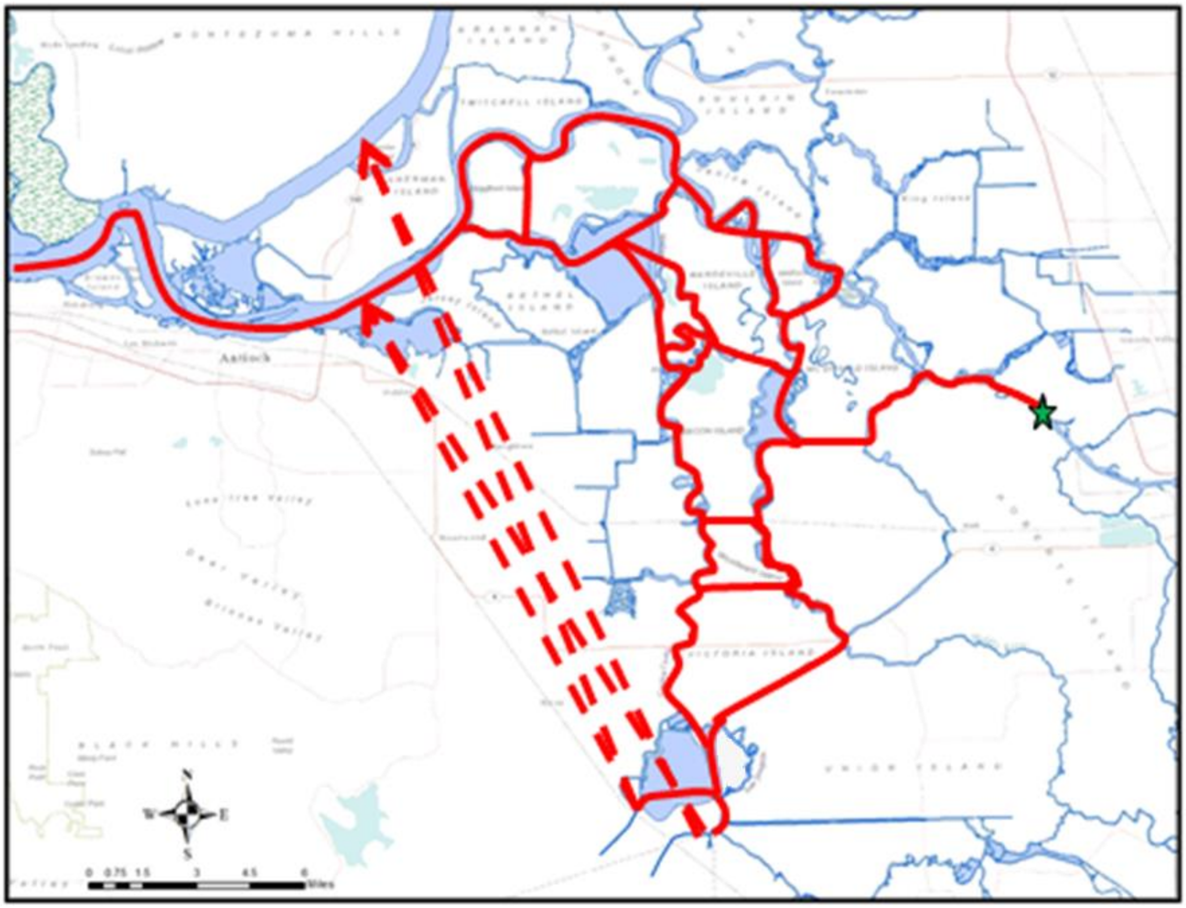


Figure 4-18 The Turner Cut route to Chipps Island for estimating overall and route-specific survival probability. Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

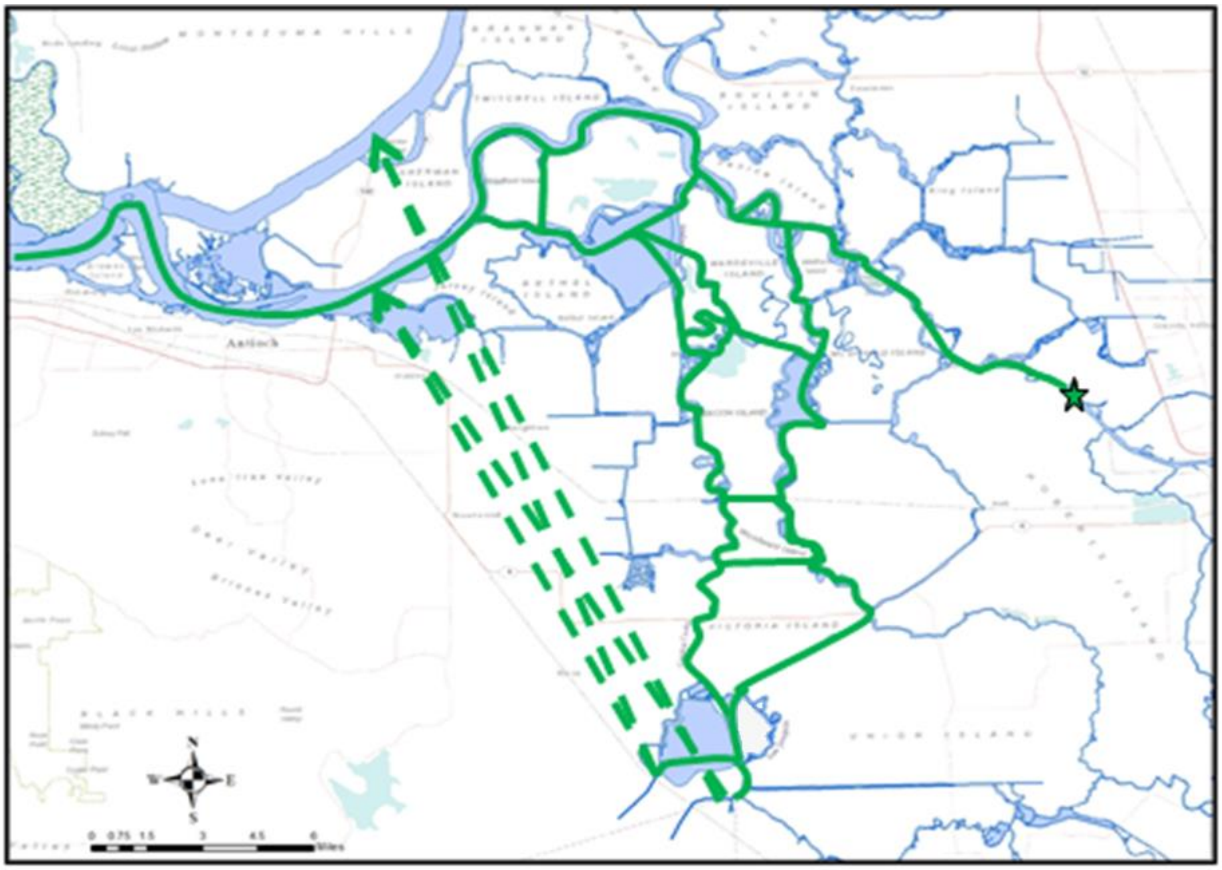


Figure 4-19 **The Mainstem route to Chipps Island for estimating overall and route-specific survival probability.** Dashed lines represent overland transport of steelhead tags in salvage trucks from an export facility to one of the release sites upstream of Chipps Island.

METHODS FOR TESTING HYPOTHESIS 4.2.2

The same methods used for Hypothesis 4.2.1 (multistate model) were employed for Hypothesis 4.2.2. As seen in Table 4-10, the route-specific survival probabilities are the sum of route-specific transition probabilities that encompass the routes. Overall survival probability incorporated the initial survival and the proportion of steelhead tags using each route. Route entrainment at Turner Cut was a parameter fit by the model (Table 4-10).

RESULTS FOR HYPOTHESIS 4.2.2 TEST

Overall survival to Chipps Island was 50.2% (SE=2.0%) (Table 4-15). Route-specific survival probability for the Turner Cut route was 27.0% (SE=3.0%) (Table 4-15). Route-specific survival probability for the Mainstem route was 56.7% (SE=2.4%) (Table 4-15). The model estimated that the majority of steelhead tags (77.6%, SE=1.6%), continued along the San Joaquin River and only 22.4% (SE=1.6%) of the steelhead tags were entrained into the interior Delta at the Turner Cut junction (Table 4-15). The model also generated detection probabilities, route entrainment probabilities, and transition probabilities (Table 4-16).

Table 4-15 Route-specific survival probabilities, Turner Cut route entrainment, overall survival, and standard errors for each estimate.

Description	Probability (%)	Standard Error (%)
Mainstem route survival	56.7	2.4
Turner Cut route survival	27.0	3.0
Turner Cut route entrainment	22.4	1.6
Overall survival	50.2	2.0

Table 4-16 Estimates and standard errors for parameters estimated in the model. s0 is the initial survival. Terms that start with "p" are detection probabilities for the upstream ("a") and downstream ("b") receivers. Terms that start with "Ψ" denote route entrainment probabilities. Terms that start with "ϕ" denote transition probabilities. Numbers following one of these terms in the left column are the arrays that the term is describing. For example, p2a is the detection probability of upstream receivers of array 2 and ϕ2,22 is the transition probability from array 2 to array 22.

	Estimate (%)	Standard Error (%)
s0	100.3	1.2
p2a	41.0	2.2
p2b	39.4	2.2
P7a	99.4	0.6
P7b	99.4	0.6
ΨA	77.6	1.6
ΨB	22.4	1.6
ϕ2,22	35.9	2.0
ϕ2,21	71.6	12.0
ϕ2,20	4.5	0.8
ϕ ,22	10.1	2.3
ϕ ,21	44.2	9.3
ϕ ,20	12.6	2.5
p22a	97.3	1.1
p22b	92.4	1.7
p21a	9.4	2.0
p21b	2.6	0.8
p20a	90.5	4.5
p20b	82.6	5.6
ϕ22,24	68.9	4.2
ϕ20,24	4.0	3.9
ϕ21,24	44.3	7.9
p24a	95.1	1.2
p24b	98.6	0.7

Survival estimated in the model was similar but lower than an estimate from another study using similar modeling approaches and data from steelhead but from another year. Survival of San Joaquin River (SJR) steelhead smolts in 2011 as estimated by a mark-recapture study for the Six-Year Study was 55% (SE=2%) (Buchanan 2013). In this study, we found the survival for this area in 2012 to be 50.2% (SE=2.0%). Acoustically tagged steelhead in this study were released at Buckley Cove, which is much closer to Chipps Island than Durham Ferry, where Six-Year Study steelhead were released.

4.2.3 TRAVEL TIME

Next, we examined how travel times varied between routes and release groups. Because survival was higher for the Mainstem versus the Turner Cut route (Table 4-15), we hypothesized that steelhead tags using the Mainstem route would have shorter travel times than tags using the Turner Cut route. We assumed that shorter travel times would lead to less exposure time to predators, and therefore higher survival.

Hypothesis 4.2.3: The travel times of steelhead tags were not significantly different between routes or release groups.

METHODS FOR TESTING HYPOTHESIS 4.2.3

Travel times (i.e., time between first detection at array 24 and last detection at array 1) were calculated for each steelhead tag that successfully migrated through each route used in the model (six transition probability and two survival probability routes) and that was detected at array 1 and array 24 (Chipps Island). We used ANOVA to test for a significant difference in travel times between release groups and two survival probability routes. We were also able to examine how the OMR flow levels affected the amount of time it took steelhead tags to reach their destination by comparing travel times of Release Groups 1 and 2 combined versus Release Group 3. For a steelhead tag to be included in the analyses, it needed to be detected at arrays 1, 2 or 7; 20 or 21 or 22; and 24 (Figure 2-3). If a steelhead tag was detected at more than one array on the same level of the schematic (Figure 4-17), it was considered to use the array on that level that the steelhead tag was last detected. The only exception to this rule was that if a steelhead tag was detected at array 20 and/or 21 (radial gates of Clifton Court Forebay and/or CVP) and array 22 (Jersey Point), the steelhead tag was considered to be detected at the export facility where it was last detected. Therefore, for the few steelhead tags that were detected at an export facility and then at Jersey Point and then at Chipps Island, the steelhead tags were identified as steelhead tags that went through the salvage operations of the export facility that last detected the steelhead tag before next being detected at Chipps Island.

RESULTS FOR HYPOTHESIS 4.2.3

We first calculated the travel times for each of the six transition probability routes across all release groups (Table 4-17). Due to the limited sample sizes (N<4) for four of the six transition probability routes, we were unable to test for significant differences. The average travel time was longest for steelhead tags using the Turner Cut to Chipps Island area via CVP route (7.2 days), and shortest for steelhead tags using the route to Chipps Island area without using Turner Cut (4.5 days) (Table 4-17).

Table 4-17 The average travel time (days), standard error, and sample size of the six routes that the model estimated route-specific transition probabilities.

Route to Chipps Island	Avg. travel time (days)	Standard Error (%)	N
Via Turner Cut	6.0	0.9	13
Without using Turner Cut	4.5	0.2	71
Via Turner Cut and SWP	4.8	N/A	1
Via SWP without using Turner Cut	-	-	0
Via Turner Cut and CVP	7.2	2.7	3
Via CVP without using Turner Cut	6.8	N/A	1

We found that the average travel time was always longer for steelhead tags in the Turner Cut route versus the Mainstem route for each release group and combined Release Groups 1 and 2 (Table 4-18). As we expected, Mainstem route steelhead tags, which had double the survivorship, had shorter travel times than the Turner Cut route steelhead tags that did not go through salvage. Likely lower exposure times to predators in the Mainstem route lead to higher survival.

Table 4-18 The mean travel time for steelhead tags using each of the two survival probability routes, standard errors (in parentheses), and sample sizes for Release Groups 1, 2, and 3, and Release Groups 1 and 2 combined.

Route	Travel Time of RG #1		Travel Time of RG #2		Travel Time of RG #3		Travel Time of RG #1&2	
	Days	N	Days	N	Days	N	Days	N
Mainstem	5.5 (0.5)	18	4.1 (0.3)	30	4.2 (0.3)	24	4.6 (0.3)	48
Turner Cut	7.1 (1.5)	6	4.8 (1.1)	6	6.5 (1.6)	5	6.0 (1.0)	12

When not combining release groups, we found that travel times for release groups (P=0.02) and route taken were both significant (P=0.02). When the data were analyzed using two release groups (1 and 2 versus 3), we found that route taken was again significant (P=0.01), where release group was no longer significant (P=0.69). These results suggest that the OMR flows tested did not affect the travel times of steelhead tags, as we would have expected travel times to be significantly different for Release Group 3 versus 1 and 2 combined. Instead, we found that significant differences only occurred in travel times when Release Groups 1 and 2 were treated separately in the statistical analysis. Travel times were longer for Release Group 1 versus 2 or 3 for both routes (Table 4-18). Because OMR flows were similar between Release Groups 1 and 2, it is unlikely that OMR flows were driving these differences.

4.3 JUNCTION-LEVEL ANALYSES

In this section, we examine how steelhead tags moved through key Delta junctions. We examine if different OMR flow conditions affected the routing of steelhead tags at three junctions along the San Joaquin River (Turner Cut, Columbia Cut, and Middle River), at the state and federal export facilities, and in the interior Delta at Railroad Cut.

4.3.1 ROUTING AT DELTA JUNCTIONS

The routing of steelhead into the interior Delta along the San Joaquin River may be affected by the activities of the export facilities, given that they can create negative river flows (toward the facilities). Previously, we found that travel times were longer for steelhead tags taking the interior Delta route compared to those that remained in the San Joaquin River (Section 4.2.3), likely leading to the observed lower survival rates for steelhead tags in the interior Delta (Section 4.2.2) due to increased time for mortality to occur. Therefore, it is important to understand if more negative OMR flows increased the proportion of steelhead tags entering the interior Delta. In this section, we examine if the probability of migrating into the interior Delta at three junctions along the San Joaquin River (Turner Cut, Columbia Cut, and Middle River) was related to the OMR flow levels tested in this study.

Hypothesis 4.3.1: The probability of steelhead tags entering the interior Delta at Turner Cut, Columbia Cut, and Middle River was not related to OMR flows.

METHODS FOR TESTING HYPOTHESIS 4.3.1

As steelhead tags travel along the Mainstem route, they reach a junction and have two options: remain in the San Joaquin River, or turn into the interior Delta. We analyzed whether the proportion of steelhead tags entering the interior Delta was related to release groups. Release group acted as a surrogate for OMR flow, with Release Group 3 representing more negative OMR flow, and Release Groups 1 and 2 representing less negative OMR flow. Junction analyses were conducted where Turner Cut, Columbia Cut, and the Middle River meet the San Joaquin River. Separate statistical tests were performed to test for differences in routing of steelhead tags at each of these three junctions. For each junction, we examined how routings differed across all three release groups, and across OMR flow levels (Release Groups 1 and 2 combined versus 3). If OMR flow affected the routing of steelhead tags, we would expect the highest proportion of tags entering into the interior Delta for Release Group 3 and more remaining on the Mainstem for Release Groups 1 and 2.

For a particular junction, a steelhead tag was included for analysis if the tag moved through the junction from upstream to downstream. The route that a tag took was defined as the last downstream array within the junction that it was detected at before leaving the junction area (i.e., the green circle in Figure 4-20 to Figure 4-22). A steelhead tag was deemed as “leaving” the junction area if it no longer was detected after being detected at a downstream junction array, or it was later detected at an array farther downstream outside of the junction area. For Turner Cut, we used data from steelhead tags that were detected at array 1 and then at arrays 2 or 7 (Figure 4-20). Array 6 was not used for this analysis because of unequal detection probabilities, as earlier described (see Section 4.2.1). For the junction at Columbia Cut, we considered steelhead tags that were detected at array 2 and then detected at array 11 or array 3 (Figure 4-21). For the junction at Middle River, we considered steelhead tags that were detected at array 3 and then at either array 4 or 13 (Figure 4-22).

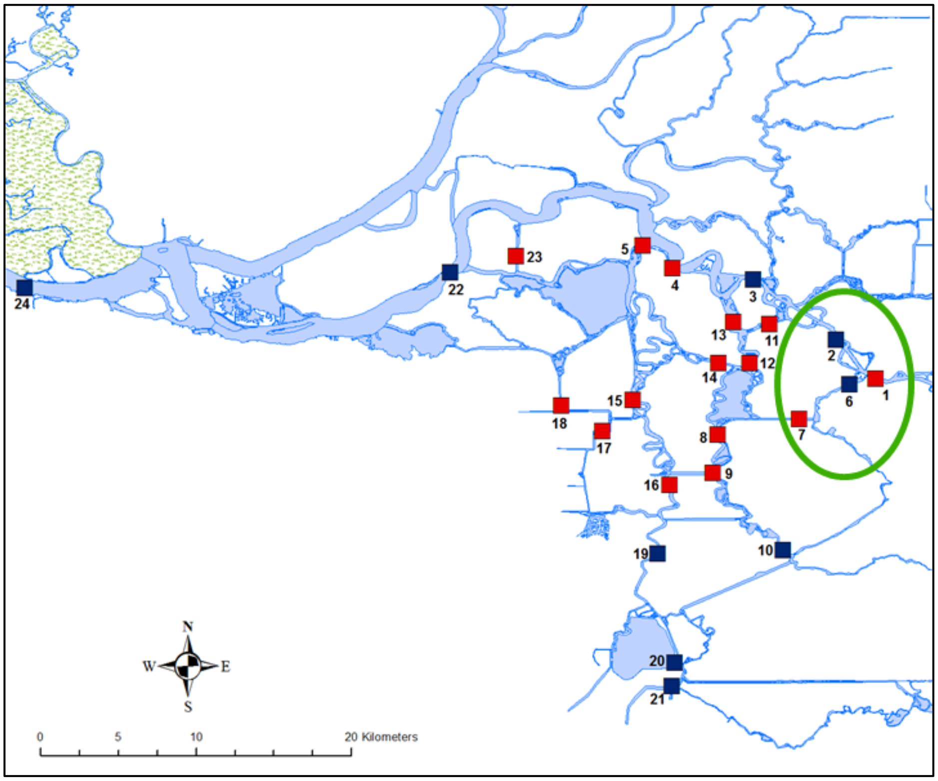


Figure 4-20 **The junction of Turner Cut as used in the junction analysis is shown in the green circle.** The red squares are sites where arrays were deployed for the Stipulation Study. The blue squares are sites where arrays were deployed for the 2012 Six-Year Study.

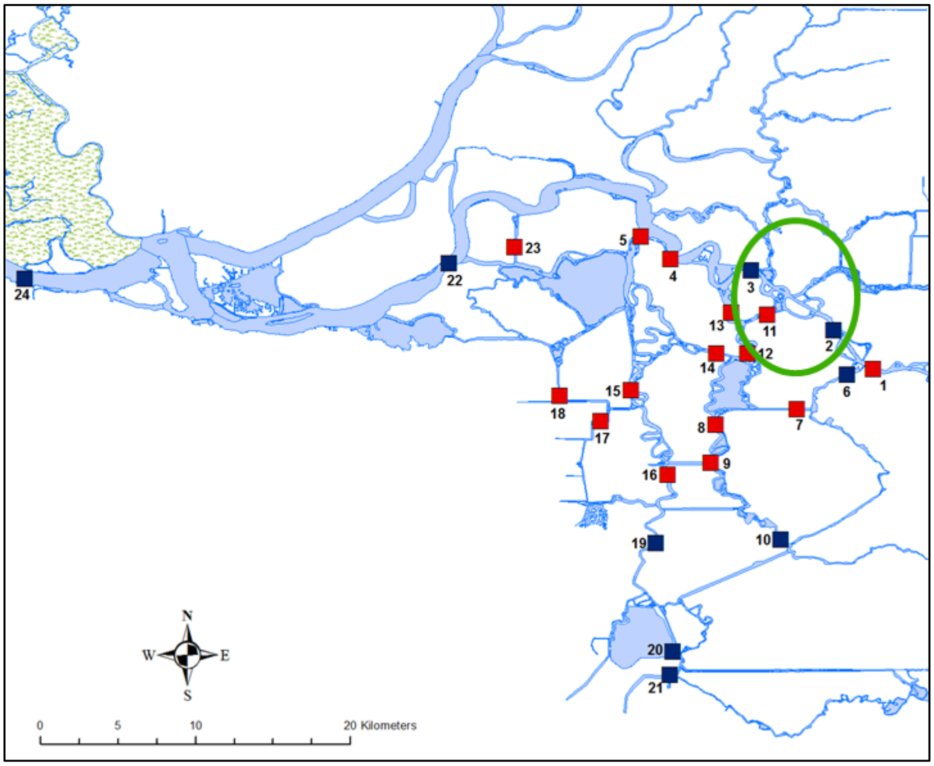


Figure 4-21 The junction of Columbia Cut as used in the junction analysis is shown in the green circle. The red squares are sites where arrays were deployed for the Stipulation Study. The blue squares are sites where arrays were deployed for the 2012 Six-Year Study.

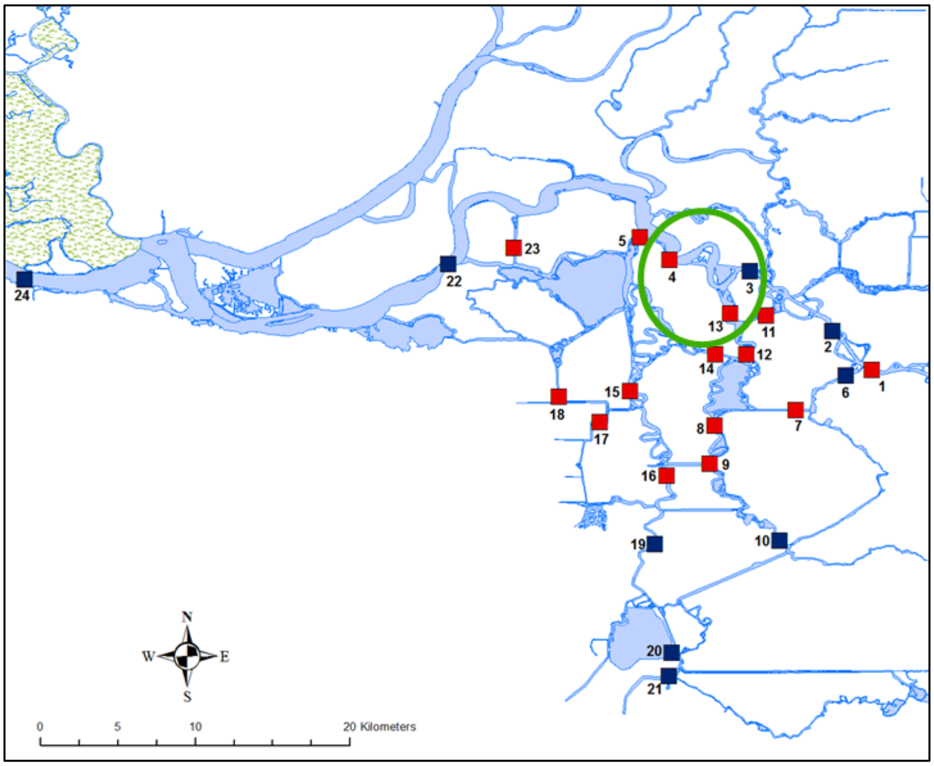


Figure 4-22 The junction of Middle River as used in the junction analysis is shown in the green circle. The red squares are sites where arrays were deployed for the Stipulation Study. The blue squares are sites where arrays were deployed for the 2012 Six-Year Study.

We examined if a significant difference in the proportion of steelhead tags migrating into the interior Delta existed between the different release groups by fitting a generalized linear model (GLM) with a binomial response variable using the R commander package (Fox 2005) of the software program R (R Project 2013). We fit the GLM with a binomial distribution of errors and a logit link function. We tested for overdispersion by comparing the residual deviance to the residual degrees of freedom using a Chi-square test. If the data were overdispersed, we re-fitted the GLM with a quasibinomial distribution of errors and a logit link function. To determine the overall effect of release group, we ran an analysis of deviance on the GLM based on either a Chi-square test or F-test depending on whether the model used a binomial or quasibinomial distribution, respectively. If we found significant differences between release groups, we then looked at how the proportion of the steelhead tags varied between release groups to identify if it occurred in a way that supported the alternative hypothesis that OMR flow affects the proportion of steelhead tags entering the interior Delta. For this to be supported, we expected a lower proportion of steelhead tags entering the interior Delta during less negative OMR flows experienced during Release Groups 1 and 2 than during the more negative OMR flows that occurred during Release Group 3.

RESULTS FOR HYPOTHESIS 4.3.1

At all three junctions, we did not find significant patterns of steelhead tag movement between release groups that would support the alternative hypothesis that release groups, a proxy for OMR flow levels tested, affected the routing of steelhead tags (Table 4-19 to Table 4-24). At Turner Cut, we found non-significant results for both the three (P=0.60) and two release (P=0.32) group analyses. At Columbia Cut, we found non-significant results for both the three (P=0.62) and two release (P=0.70) group analyses. At the Middle River, we found a significant result for the three (P<0.01) group analysis but a non-significant result for the two release group analyses (P=0.88).

For Middle River, the significant result found across three release groups was due to a lower proportion of steelhead tags migrating into the interior Delta for Release Group 2 (2.2%) versus Release Groups 1 and 3. We found that steelhead tags from Release Group 1, which experienced the less negative OMR flows, had the highest probability of migration into the Middle River (25.0%). Release Group 3, which was the most negative average OMR flow treatment, had an intermediate number of steelhead tags migrating at the Middle River (13.2%). If OMR flows were affecting movement at the Middle River, we would have expected tags from Release Groups 1 and 2 (less negative OMR flows) to have similar proportion, with tags from Release Group 3 (more negative OMR flows) having the highest proportion. However, when the data were analyzed using only two release groups, we found a similar proportion of steelhead tags entering the interior Delta between the less negative OMR flow treatment (12.2%) and the more negative OMR flow treatment (13.2%). Therefore, the differences in movement observed at the Middle River were unrelated to OMR flows observed during this study.

Table 4-19 Number of steelhead tags detected for each release group at the downstream SJR array (array 2) and the interior Delta array (array 7) after being detected at the upstream array (array 1) at Turner Cut.

Release Group	SJR Array 2	Interior Array 7
1	75	54
2	82	60
3	76	44
Total	233	158

Table 4-20 Number of steelhead tags detected for each release group at the downstream SJR array (array 3) and the interior Delta array (array 11) after being detected at the upstream array (array 2) at the Columbia Cut junction.

Release Group	SJR Array 3	Interior Array 11
1	40	17
2	47	28
3	41	24
Total	128	69

Table 4-21 Number of steelhead tags detected for each release group at the downstream SJR array (array 4) and the interior Delta array (array 13) after being detected at the upstream array (array 3) at the Middle River junction.

Release Group	SJR Array 4	Interior Array 13
1	27	9
2	45	1
3	33	5
Total	105	15

Table 4-22 Number of steelhead tags detected for each release group at the downstream SJR array (array 2) and the interior Delta array (array 7) after being detected at the upstream array (array 1) at Turner Cut. Less negative OMR flow treatments are Release Groups 1 and 2, and more negative OMR flow treatment is Release Group 3.

Release Group	SJR Array 2	Interior Array 7
Less negative OMR flows (Groups 1 and 2)	157	114
More negative OMR flows (Group 3)	76	44
Total	233	158

Table 4-23 Number of steelhead tags detected for each release group at the downstream SJR array (array 3) and the interior Delta array (array 11) after being detected at the upstream array (array 2) at the Columbia Cut junction. Less negative OMR flow treatments are Release Groups 1 and 2, and more negative OMR flow treatment is Release Group 3.

Release Group	SJR Array 3	Interior Array 11
Less negative OMR flows (Groups 1 and 2)	87	45
More negative OMR flows (Group 3)	41	24
Total	128	69

Table 4-24 Number of steelhead tags detected for each release group at the downstream SJR array (array 4) and the interior Delta array (array 13) after being detected at the upstream array (array 3) at the Middle River junction. Less negative OMR flow treatments are Release Groups 1 and 2, and more negative OMR flow treatment is Release Group 3.

Release Group	SJR Array 4	Interior Array 13
Less negative OMR flows (Groups 1 and 2)	72	10
More negative OMR flows (Group 3)	33	5
Total	105	15

The reliability of these results rests on the assumption that detection probabilities did not vary between release groups. Variability in detection probabilities at a junction across release groups would confound results because differences in steelhead tag routing could be due to differences in detection probability instead of true differences in steelhead tag movement. Previously (Section 4.2.1), we examined how detection probability varied across release groups for arrays 6 and 7 downstream of the Turner Cut junction. We found that detection probability varied across release groups for array 6, but not array 7. Therefore, we decided to use array 7 in all future analyses (including this one). This test was possible because arrays 2, 6, and 7 are dual arrays that allowed an independent probability of detection to be estimated. While this is not the case for the Middle River junction since arrays 4 and 13 were not set up as a dual array (Figure 4-23), Columbia Cut junction arrays are all dual arrays (Figure 4-24), so we could estimate release-group detection probabilities using Manly-Parr estimates (see Section 4.2.1 for detailed methods). The number and the location of receivers at the Columbia Cut junction are described in Table 4-25 and the detection probabilities for the three release groups are shown in Table 4-26.

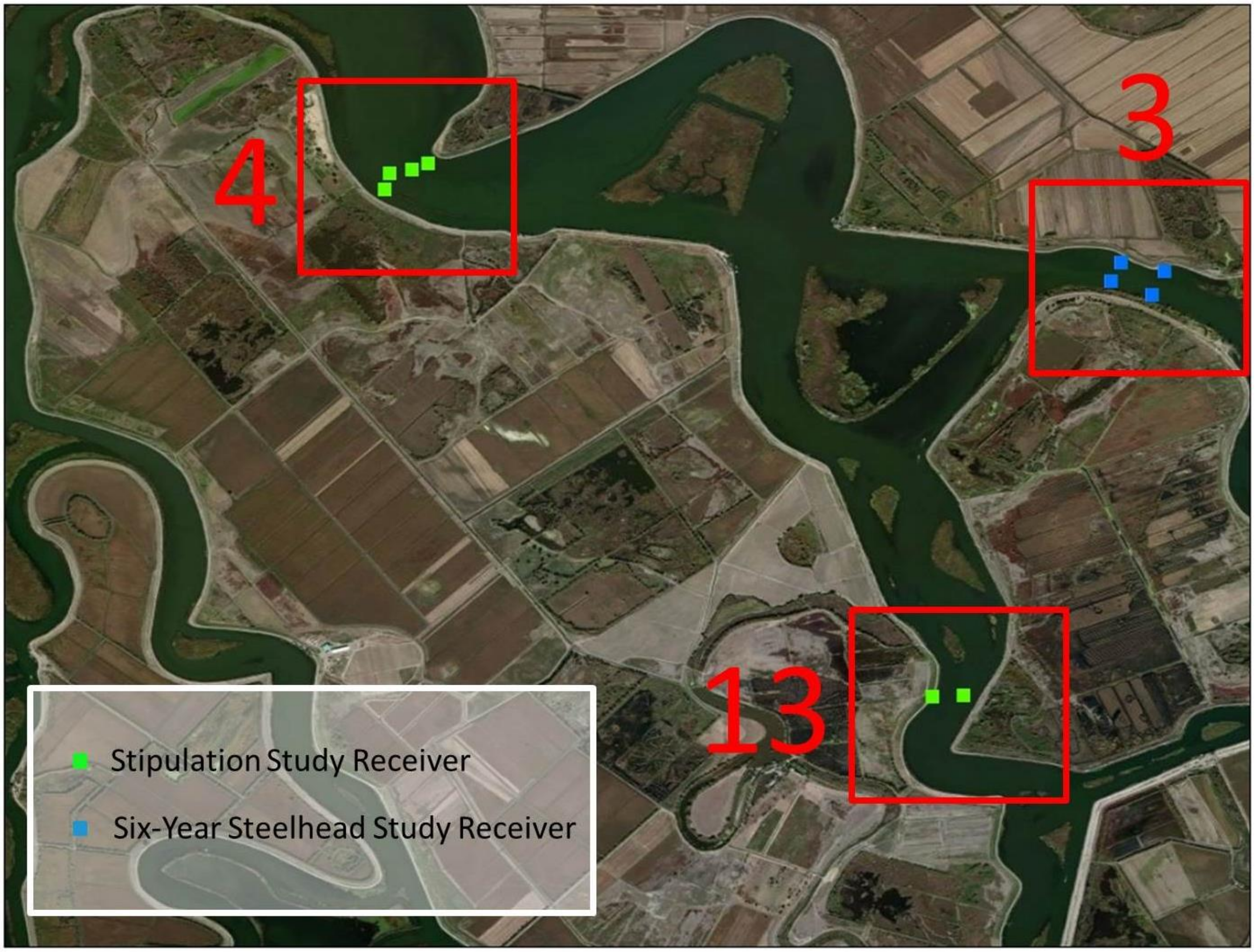


Figure 4-23 A satellite image of the Middle River junction with the placement of receiver arrays shown. Array 3 was deployed for the Six-Year Study, and arrays 4 and 13 were deployed for the Stipulation Study. Base map produced using Google Earth.

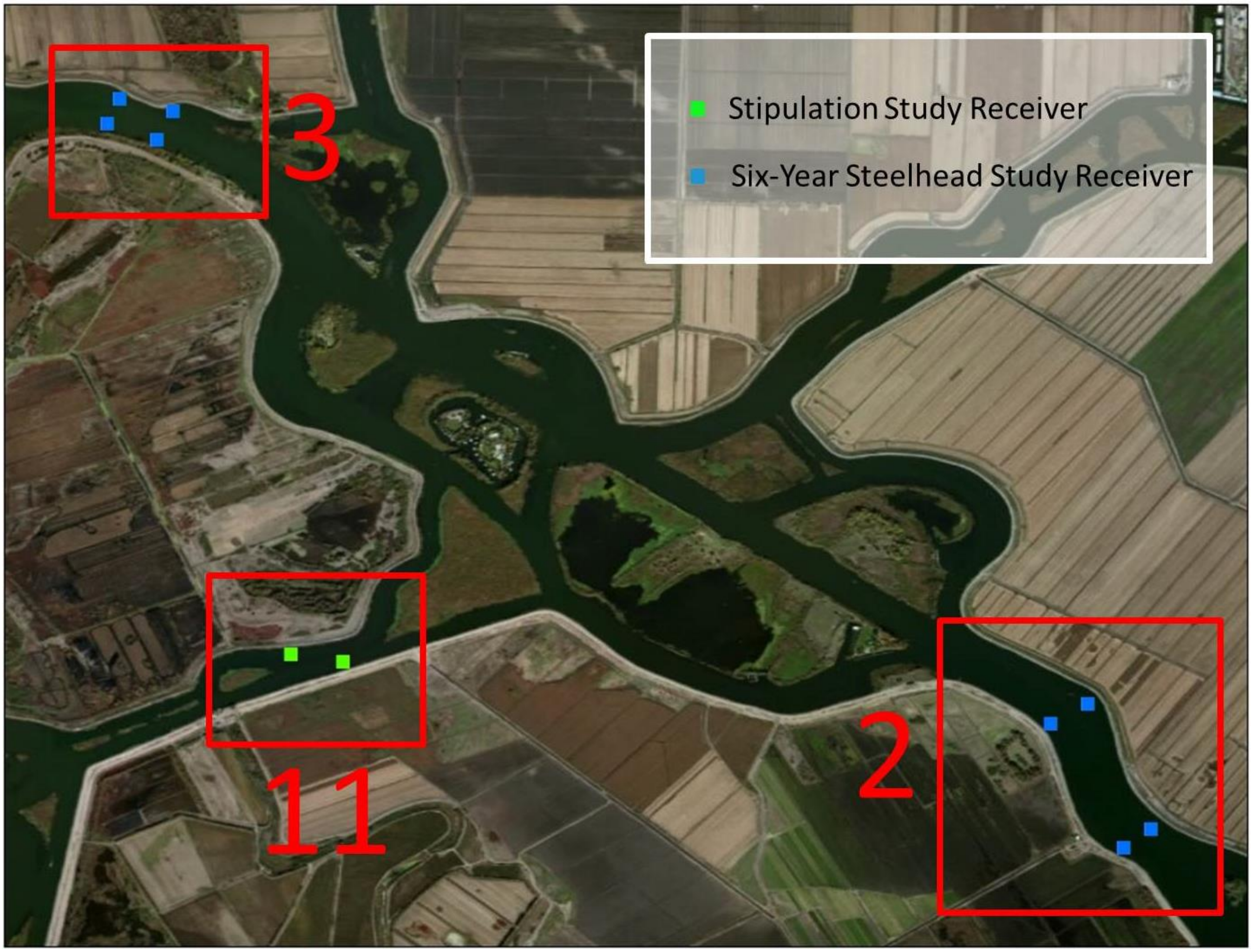


Figure 4-24 **A satellite image of Columbia Cut with the placement of receiver arrays shown.** Arrays 2 and 3 were deployed for the Six-Year Study, and array 11 was deployed for the Stipulation Study. Base map produced using Google Earth.

Table 4-25 Array number, receiver location (upstream or downstream), receiver code, station name, and latitude and longitude (decimal degrees).

Array	Upstream (A) or Downstream (B)	Receiver Code	Station Name	Latitude	Longitude
3	A	300903	MFE.1	38.0524	-121.5111
3	A	300904	MFE.2	38.0539	-121.5104
3	B	300905	MFW.1	38.0533	-121.5136
3	B	300906	MFW.2	38.0544	-121.5130
11	A	301009	8A	38.0267	-121.5020
11	B	301001	8B	38.0270	-121.5046

Table 4-26 Manly-Parr estimates of detection probabilities p) for Release Groups 1, 2, and 3 for array 3 at the Columbia Cut junction. p1 is the detection probability of the upstream receiver(s), p2 is the detection probability of the downstream receiver(s), and p is the overall detection probability for the array. All detection probabilities are expressed as percentages.

Array 3			
Release Group	**1**	**2**	**3**
p_1	100	96	100
p_2	95	100	100
p	100	100	100

Array 11			
Release Group	**1**	**2**	**3**
p_1	81	86	75
p_2	97	100	100
p	100	100	100

We found that detection probabilities at the array-level were 100% across all arrays and release groups at the Columbia Cut junction (Table 4-26). Therefore, the assumption of consistent detection probabilities appears to be met for arrays 3, and 11. For this reason, we feel the findings of the analysis that the OMR flow treatments tested likely did not affect the movement of steelhead tags at Columbia Cut are valid given consistent detection probabilities.

4.3.2 MOVEMENT AT EXPORT FACILITIES

Because water is exported out of both the SWP and CVP facilities in the Delta, and mortality varies for fish entering each facility (Gingras 1997, Clark et al. 2009), understanding how pumping at each facility influences fish movement could help managers protect sensitive fish species. The relative amount of flow entering each facility may influence the relative movement of steelhead toward each facility. Therefore, we examined how the arrival of steelhead tags at each facility may have been influenced by the proportion of flow entering each facility.

Hypothesis 4.3.2: Steelhead tag arrival at each facility was not related to the proportion of total export flow entering SWP.

METHODS FOR TESTING HYPOTHESIS 4.3.2

We examined if the arrival of steelhead tags at an export facility was related to the proportion of water entering that export facility. The arrays used for analysis were arrays 20 and 21. We summed flow across all Clifton Court Forebay gates for the SWP, and measured export flow for the CVP. The proportion of total water entering each facility was quantified for 2-hour periods, which was the highest resolution flow data available for the CVP facility. Next, the steelhead tag arrival times at each facility were paired with the appropriate 2-hour flow proportion. Steelhead tags were only counted at the facility where they were first detected. Data were pooled across release groups. A steelhead tag was included only if flows were greater than zero at either or both facilities during their 2-hour arrival period. A t-test was applied to examine if the proportion of total flow entering SWP (i.e., the radial gates of Clifton Court Forebay) differed for steelhead tags arriving at the SWP versus CVP. We expected that a higher proportion of flow would be entering the SWP when steelhead tags arrived at the SWP than when steelhead tags arrived at the CVP.

RESULTS FOR HYPOTHESIS 4.3.2

While the t-test did not find a significant result, the average 2-hour proportion of flow entering the SWP was greater when a steelhead tag was first detected at array 20 (mean=0.6, SE=0.1) than when a steelhead tag was first detected at array 21 (mean=0.4, SE=0.1). Therefore, while there was great variability in the proportion of flow when a steelhead tag arrived at an export facility, on average there was a greater proportion of water arriving at an export facility when a steelhead tag was arriving at that export facility (Figure 4-25).

These results indicate that the arrival of steelhead smolts toward each export facility was not significantly related to proportional flow to a facility on a 2-hour period. Qualitatively, however, it appeared that the movement of steelhead tags might be influenced by the relative flow amount entering each facility. By coordinating the relative export levels at each facility, sensitive fish species could potentially be routed toward the facility perceived to have lower risks of fish mortality for the given time of year.

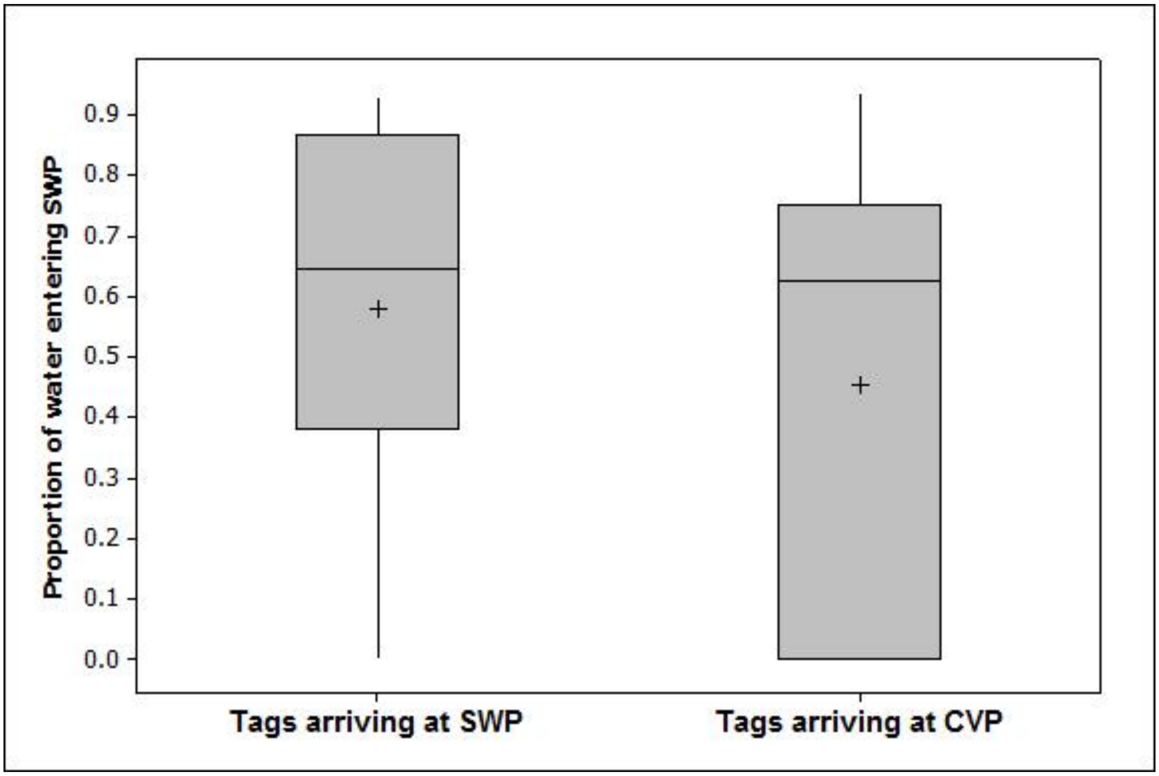


Figure 4-25 The proportion of water entering the SWP (i.e., entering the radial gates of Clifton Court Forebay) when steelhead tags arrived at the radial gates of Clifton Court Forebay (SWP) and at the CVP. The gray rectangle indicates the middle 50% (interquartile range) of the data, the horizontal line indicates the median, the "+" indicates the mean, and vertical lines extend to the highest data value within the upper limit (= Q3 + 1.5 [Q3 - Q1]) and to the lowest value within the lower limit (= Q1- 1.5 [Q3 - Q1]).

4.3.3 MOVEMENT AT RAILROAD CUT

During the Stipulation Study, steelhead tags were used as “sentinels” to identify when wild salmonids were likely approaching the export facilities to determine when more protective actions were needed for wild fish. When steelhead tag detections at Railroad Cut (array 9, Figure 4-26) exceeded a threshold (5% of fish reaching Railroad Cut), managers triggered a management option to reduce south Delta export flows in an effort to provide additional protection for ESA-listed salmonids. The trigger was meant to reduce Delta exports, leading to less negative OMR flows and less risk of smolts moving toward the export facilities and potentially becoming entrained. Therefore, we tested the effectiveness of the trigger by examining how the routing of steelhead tags toward the export facilities at Railroad Cut varied before and after the trigger and across release groups. We also examined the effect of the OMR flows tested, by examining how the proportion of tags moving toward or away from the export facilities varied with OMR flow conditions during steelhead tag routing.

Hypothesis 4.3.3: The movement patterns of steelhead tags after passing through Railroad Cut were not affected by OMR flows.

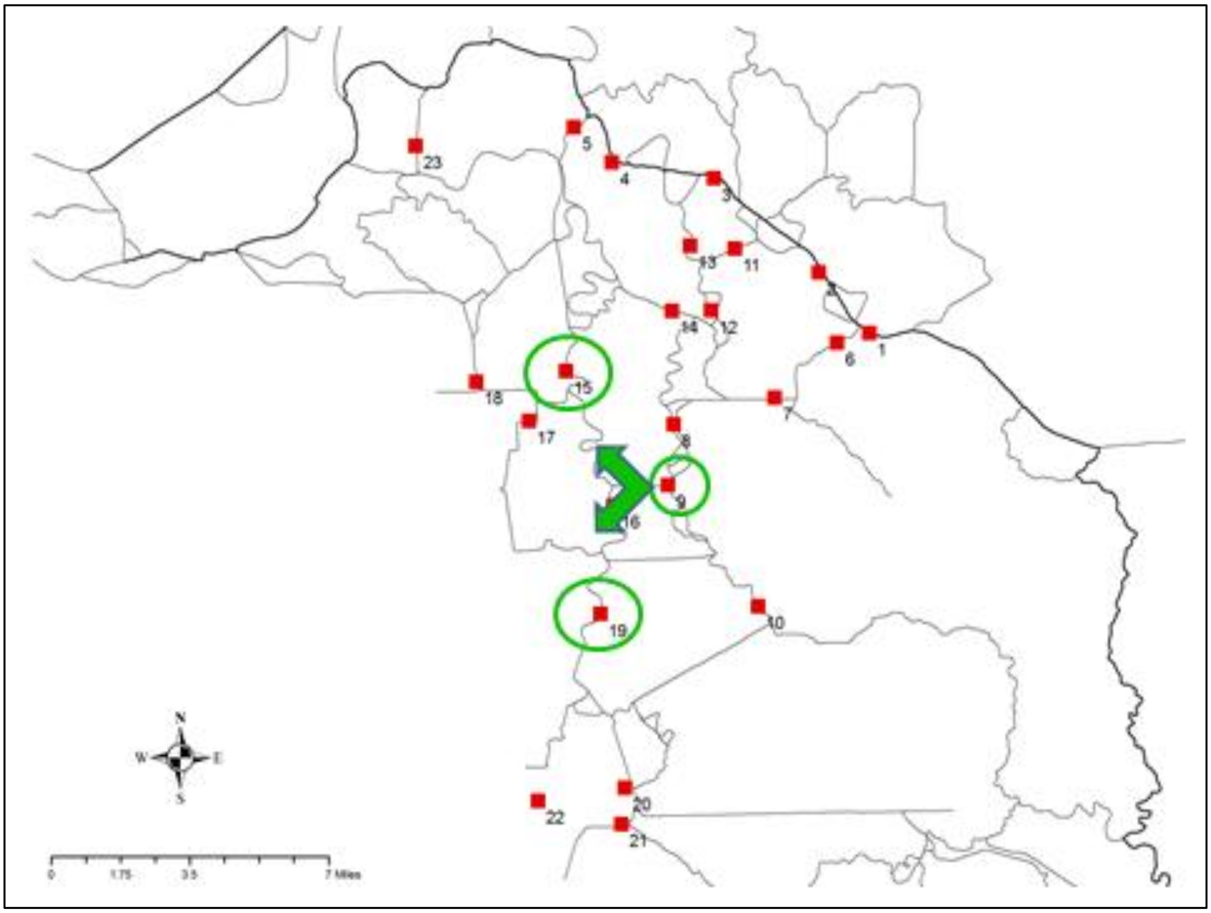


Figure 4-26 **Steelhead tags arriving at Railroad Cut (array 9) were either routed away from the export facilities (array 15) or toward the facilities (array 19).**

METHODS FOR TESTING HYPOTHESIS 4.3.3

We examined if a greater proportion of steelhead tags travelled away from the export facilities (array 15) than toward the facilities (array 19) before and after the trigger was implemented to reduce OMR flows and across release groups. Therefore, we only used steelhead tags that were detected at array 9 and then detected at either or both downstream arrays (i.e., array 15 or 19). For steelhead tags detected at both downstream arrays, we used the array that detected the steelhead tag last to delineate the final route of that tag. When the day that the management option had been triggered and the less negative flows were observed to occur was identified by examining the OMR flow data (Figure 2-1) and identified as the day that the daily average OMR level was at or below -1,250 cfs. This date was determined to be April 24, May 11, and May 26 for Release Groups 1, 2, and 3, respectively. Applying similar statistical methods as Hypothesis 4.3.1, using GLMs, we examined if routing of steelhead tags differed between pre- and post-triggering of the management conditions and/or between release groups. We analyzed the data as three release groups as well as two groups, where Release Groups 1 and 2 were pooled and considered the less negative OMR flow treatment, and Release Group 3 as the more negative OMR flow treatment.

We also directly examined the effect of OMR flow on routing at Railroad Cut. We examined how routing at Railroad Cut was affected by a measurement of OMR flow while a steelhead tag was moving across Railroad Cut toward the downstream arrays of interest. Therefore, in separate GLMs, we examined if the proportion of steelhead tags moving south or north from the export facilities (i.e., last detected at array 15 or 19) was related to one or more of the following OMR flow variables:

1. Average OMR flow that the steelhead tag experienced from the day that the steelhead tag was first detected at array 9 to the day when it was first detected at the downstream array (array 15 or 19) that last detected the steelhead tag.
2. Average OMR flow that the steelhead tag experienced from the day that the steelhead tag was last detected at array 9 to the day when it was first detected at the downstream array that last detected the steelhead tag.
3. Average OMR flow that the steelhead tag experienced for the day that the steelhead tag was last detected at array 9.
4. Average minimum OMR flow that the steelhead tag experienced from the day the steelhead tag was last detected at array 9 to the day it was first detected at the downstream array that last detected the steelhead tag.
5. Average maximum OMR flow from the day that the steelhead tag was last detected at array 9 to the day it was first detected at the downstream array that last detected the steelhead tag.
6. Average OMR flow on the day that steelhead tag was last detected at the downstream array that last detected the steelhead tag.
7. Average OMR flow on the day that steelhead tag was first detected at the downstream array that last detected the steelhead tag.
8. Average OMR flow on the day that steelhead tag was last detected at the downstream array that first detected the steelhead tag.
9. Average OMR flow on the day that steelhead tag was first detected at the downstream array that first detected the steelhead tag.

RESULTS FOR HYPOTHESIS 4.3.3

We examined the detections by the upstream and downstream receivers of array 15 and 19 (Table 4-27) and found detection probabilities to be consistent between release groups at the arrays (Table 4-28). Therefore, differences in routing between release groups can be attributed to actual movement differences and not to variation in detection probability.

Table 4-27 Array number, receiver location (upstream or downstream), its receiver code, station name, and latitude and longitude (decimal degrees).

Array	Upstream (A) or Downstream (B)	Receiver Code	Station Name	Latitude	Longitude
15	A	301015	15A	37.9828	-121.5810
15	B	301053	15B	37.9844	-121.5818
19	A	300885	OR4D.2	37.8953	-121.5667
19	A	300884	OR4D.1	37.8950	-121.5661
19	B	300883	OR4U.2	37.8939	-121.5675
19	B	300882	OR4U.1	37.8938	-121.5667

Table 4-28 Manly-Parr estimates of detection probabilities p) for Release Groups 1, 2, and 3 for arrays 15 and 19. p1 is the detection probability of the upstream receiver(s), p2 is the detection probability of the downstream receiver(s), and p is the overall detection probability for the array. Given the detection data for Release Group 1 at array 15, only the detection probabilities at the downstream receiver could be estimated. All detection probabilities are expressed as percentages.

Array 15			
Release Group	**1**	**2**	**3**
p_1	N/A[a]	71	67
p_2	0	100	100
p	N/A[a]	100	100

Note:

[a] Detection probability not calculated because no fish were detected at both upstream and downstream receivers and the downstream receiver(s) only resulting in a division by zero error.

Array 19			
Release Group	**1**	**2**	**3**
p_1	100	100	100
p_2	100	100	100
p	100	100	100

Other than in Release Group 1 for array 15 where we could not estimate the detection probability at the array-level, for all other periods and arrays, detection probabilities were all 100% (Table 4-28). No steelhead tags were detected at the downstream receiver at array 15 during Release Group 1, making the calculation of detection probability at the upstream receiver impossible. Given that the only estimate of detection probabilities at array 15 during Release Group 1 was 0% for the downstream receiver, and all other detection probabilities for Release Groups 2 and 3 were higher, the detection probabilities for array 15 might be confounded with release groups. To investigate detection probability at array 15 further, we calculated the array-level detection probability for Release Groups 1 and 2 combined to ensure that detection probabilities remained high between both less negative (Groups 1 and 2) and more negative (Group 3) OMR flow treatments. We estimated an array-level detection probability of 80.4% for Release Groups 1 and 2 combined, indicating that detection probability at array 15 was high (>80%) for both OMR flow treatment groups.

The observed effect caused by the triggering of reduced exports occurred after more than 90% of the steelhead tags (68/75) had already passed the east end of Railroad Cut (array 9), which provided a limited sample size (Table 4-29) to examine the effect of the management option. The majority of steelhead tags (6/7) that passed Railroad Cut after the triggering of less negative OMR flows had occurred went south (Table 4-29). Due to the limited sample sizes, we did not statistically analyze the effect of the management option, but we did examine if the release group had a significant effect. In the three release group analysis, the overall logistic regression was not significant (P=0.17). In the two release group analysis, the overall logistic regression was marginally significant (P=0.08).

Table 4-29 The number of steelhead tags detected pre- and post-triggering of the management option for the three release groups.

	Pre-Trigger Release Group 1	Post-Trigger Release Group 1	Pre-Trigger Release Group 2	Post-Trigger Release Group 2	Pre-Trigger Release Group 3	Post-Trigger Release Group 3
Northern receiver array (15)	10	1	7	0	3	0
Southern receiver array (19)	12	6	18	0	18	0

When examining the effect of OMR flows observed directly in GLMs, all of the nine independent variables were found not to be significant except for the test that examined the average OMR flow on the day that a steelhead tag was first detected at either of the downstream arrays (P=0.05, Table 4-30). The relationship showed an increasing probability of steelhead tags moving toward the export facilities as OMR flow values become more negative (Table 4-31, Figure 4-27).

Table 4-30 P-values for the logistic regression examining whether the following independent variables were significantly related to the whether a steelhead tag was last detected at array 15 or 19 after passing through Railroad Cut.

Independent Variable	P
Average OMR flow that the steelhead tag experienced from the day that the steelhead tag was first detected at array 9 to the day when it was first detected at the downstream array (array 15 or 19) that last detected the steelhead tag.	0.146
Average OMR flow that the steelhead tag experienced from the day that the steelhead tag was last detected at array 9 to the day when it was first detected at the downstream array that last detected the steelhead tag.	0.124
Average OMR flow that the steelhead tag experienced for the day that the steelhead tag was last detected at array 9.	0.157
Average minimum OMR flow that the steelhead tag experienced from the day the steelhead tag was last detected at 9 to the day it was first detected at the downstream array that last detected the steelhead tag.	0.129
Average maximum OMR flow from the day that the steelhead tag was last detected at array 9 to the day it was first detected at the downstream array that last detected the steelhead tag.	0.128
Average OMR flow on the day that steelhead tag was last detected at the downstream array that last detected the steelhead tag.	0.070
Average OMR flow on the day that steelhead tag was first detected at the downstream array that last detected the steelhead tag.	0.054
Average OMR flow on the day that steelhead tag was last detected at the downstream array that first detected the steelhead tag.	0.131
Average OMR flow on the day that steelhead tag was first detected at the downstream array that first detected the steelhead tag.	0.050

Table 4-31 Coefficient estimates, standard errors, and Z and P-values for the constant and factor of average OMR flow on the day that the steelhead tag was first detected at the downstream array that first detected it. The overall P-value for this logistic regression was 0.05.

Predictor	Coefficient	Standard Error	Z	P
Constant	0.228	0.653	0.349	0.727
OMR flow	<0.001	<0.001	1.872	0.061

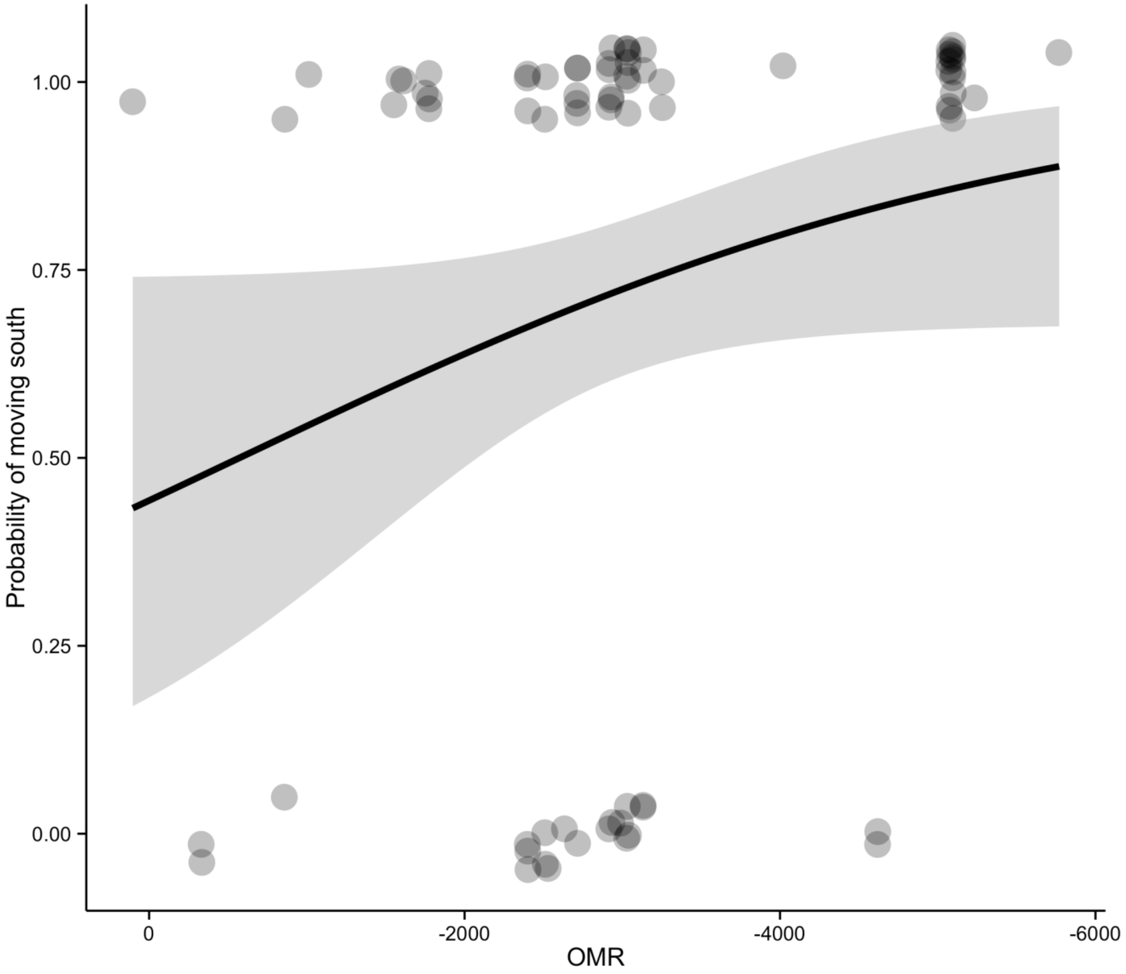


Figure 4-27 The probability of steelhead tags moving south (toward the export facilities) for the observed range of OMR flow values from a GLM with the line of best fit and the shaded area represents the 95% confidence interval. Data points for the observed OMR values were either moving south (1) or north (0). Given the overlap of data points, they were jittered so more of them can be seen in the figure.

The small sample size limited our ability to examine the effectiveness of the trigger on the movement of steelhead tags. If a trigger is implemented in the future, we recommend ensuring that a larger number of tagged fish are approaching the area before and after the management option has been observed to come into effect. We recommend that future tagging studies be conducted under a wider range of OMR flows to better understand how the range of possible OMR flows influence fish routing near the export facilities. As tidal conditions may contribute to changes in fish behavior, any future studies should also be conducted under shorter time periods with greater replication.

This page intentionally left blank.

5 DISCUSSION

CHAPTER SUMMARY:

We address the following four questions in this chapter:

1. Did OMR flows affect steelhead tag movement and survival?
2. How effective was real-time monitoring and management?
3. What were the limitations of the experimental design and how could they be improved?
4. What future experiments and methods are recommended?

Overall, under the OMR flows tested, there was little influence of OMR flows on steelhead tag movement during this study. There was limited evidence of OMR flows tested influencing steelhead tag routing at Railroad Cut in the interior Delta and arrival timing at the SWP Clifton Court Forebay radial gates. The influence of the OMR flows tested on steelhead tag behavior appears to be limited to a short distance from the SWP and CVP projects. Future studies should focus on how smolt movement and survival at Railroad Cut and south (toward the export facilities) may be influenced by a wider range of OMR flow conditions than those examined in this study. More than 90% of steelhead tags passed the real-time monitoring detection point before the effects of triggered changes to OMR flow conditions were observed (i.e., OMR flows reached -1,250 cfs). While improvements to the experimental design of any future real-time monitoring study could be completed, this study points to the inability to effectively use tagged steelhead smolts as sentinels to trigger export changes. This study also provides evidence of the challenges of managing Delta flow conditions in real-time. Because there was little evidence that altering OMR flow conditions within the range of values examined in this study would alter the movement of fish in a meaningful way, these results do not provide evidence that real-time monitoring could be used to protect salmonids.

5.1 DID OMR FLOWS AFFECT STEELHEAD TAG MOVEMENT AND SURVIVAL?

We found no evidence that the OMR flows tested affected the routing of steelhead tags along the San Joaquin River corridor. The routing of steelhead tags at Turner Cut, Columbia Cut, or where the Middle River meets the San Joaquin River was not related to release groups (and therefore the experimental OMR flow treatments evaluated in this study). The limited influence of OMR flows on steelhead tag routing along the San Joaquin River was expected due to the limited differences in modeled flow routing observed under different OMR flow treatments tested (Cavallo et al. 2012). The range of OMR flows that occurred during the study did not capture the historical operating range of flows and was conducted when the HORB was in place. Yet, the steelhead tagging results, paired with hydrodynamic modeling, indicated that OMR flows may have very limited ability to influence the migration of salmonid smolts into the interior Delta within the range of the values and conditions observed in the study.

While no evidence of an influence of OMR flow conditions on routing was found at the San Joaquin River junctions, there was some marginally significant evidence of differences in the routing of steelhead tags at Railroad Cut. This junction is closer to the export facilities and occurs along the OMR corridor. Therefore, a stronger influence of OMR flows on steelhead tag movement at Railroad Cut compared to river junctions along the San Joaquin River was not surprising. These results may be evidence of a more localized area of influence of the export facilities on salmonid smolt movement, extending as far north as Railroad Cut. However, due to sub-optimal receiver placement in the interior Delta, we were unable to precisely examine the spatial extent of influence of OMR flows on smolt movement. While this study had an elaborate deployment of telemetry equipment, we believe that more receivers, tagged fish, and release sites are needed along with different operation scenarios at CVP and SWP to better examine if OMR flows affect steelhead movement and survival.

When examining system-level steelhead tag behavior, we found no consistent pattern between release groups, suggesting that OMR flows as tested may have had minimal effect on the general movement patterns of steelhead tags during the study. In particular, we found that the “point of no return,” defined as the point where steelhead tags in the interior Delta no longer arrived at Chipps Island without assistance (through salvage operations at export facilities), changed only slightly among OMR flow treatments evaluated during this study. While it was farther north for Groups 1 and 2 compared to Group 3, the difference was only two arrays (Figure 4-4 to Figure 4-6). In addition, this line being farther south for Group 3 is contradictory to what should have been expected under more negative OMR flows for Group 3, where the point of no return was expected to have been farther north if OMR flows were controlling the point of no return.

Unfortunately, we were unable to examine how OMR flows influenced survival of steelhead tags, due to the failure of the USER model to converge on individual release group models. Limited sample sizes for each individual release group likely caused the model to not converge on a solution. We recommend that future tagging studies have ample sample sizes to examine the effect of OMR flows on survival.

As part of the route-level analysis, we found no significant evidence that travel times were related to OMR flows within the ranges examined in this study, as seen in Section 4.2.3. To provide further evidence of the limited influence of OMR flow conditions on steelhead tag travel time, we examined the cumulative detections through time that occurred at many of the arrays in this study (Figure 5-1 to Figure 5-3). At most arrays, we did not see major differences in arrival timing between Group 2 (less negative OMR flows) and Group 3 (more negative OMR flows), suggesting that OMR flows had minimal effect on the general timing patterns of when steelhead tags reached an array.

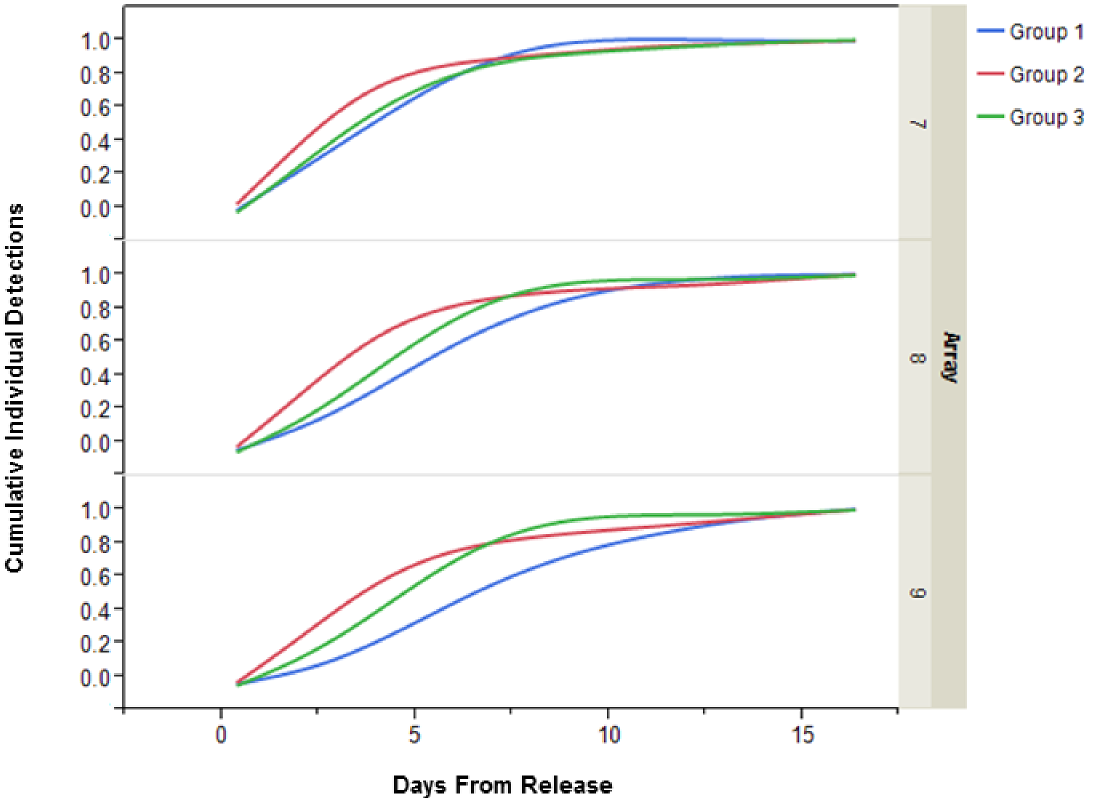


Figure 5-1 The cumulative detection curves for Groups 1, 2, and 3 at arrays 7, 8, and 9.

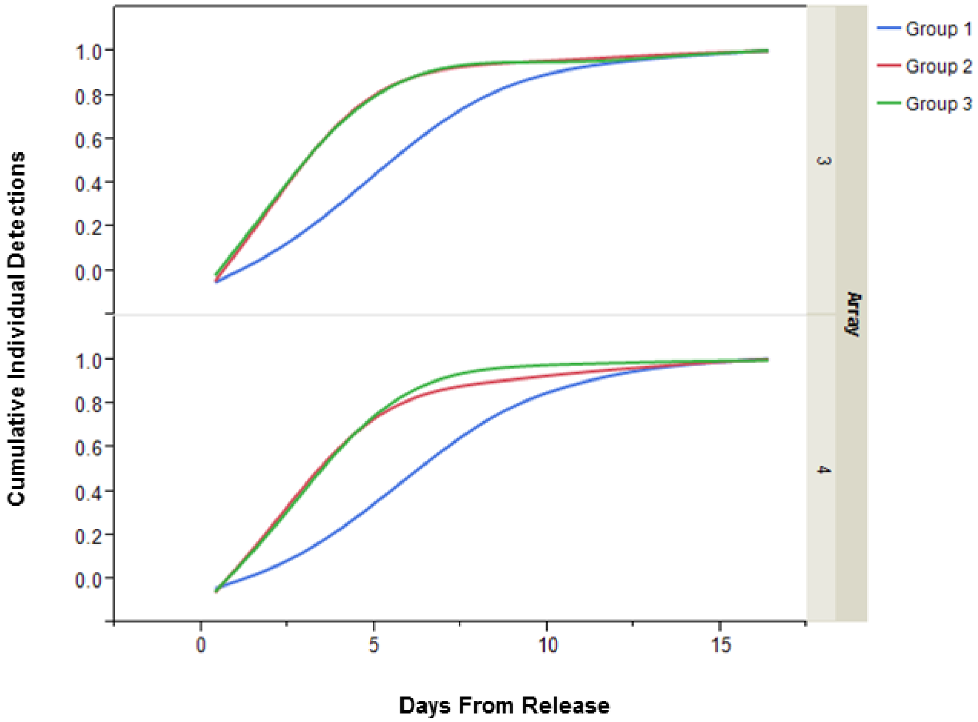


Figure 5-2 The cumulative detection curves for Groups 1, 2, and 3 at arrays 3 and 4.

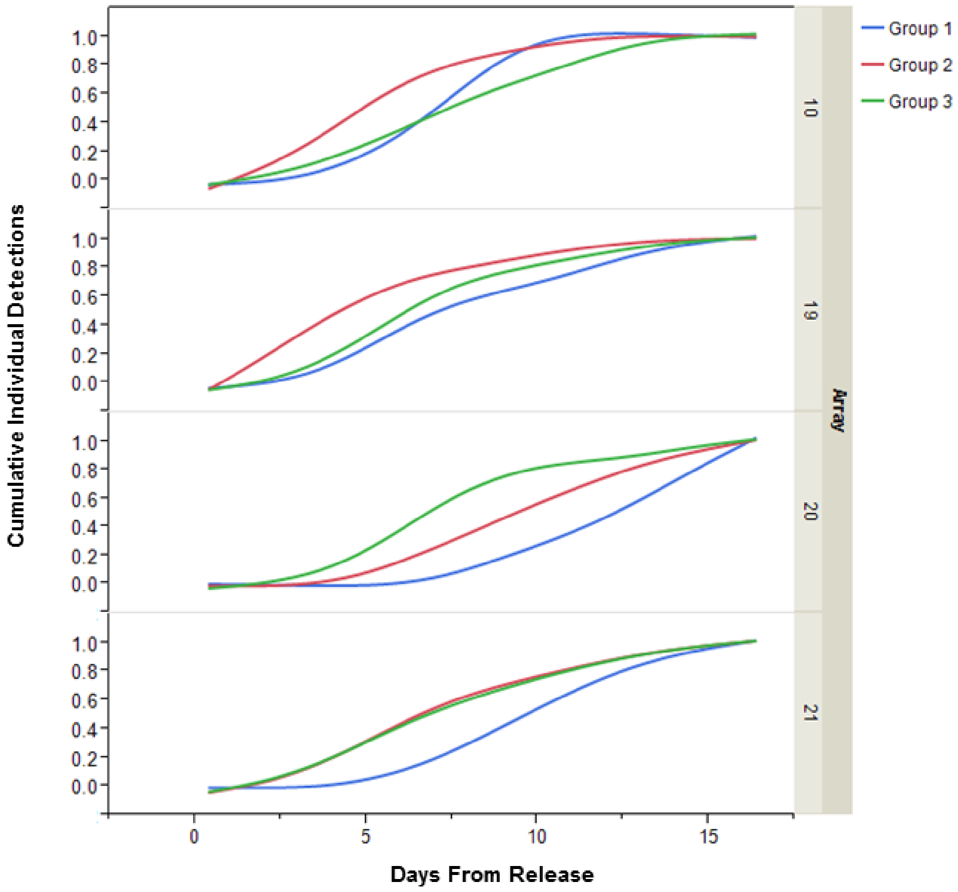


Figure 5-3 The cumulative detection curves for Groups 1, 2, and 3 at arrays 10, 19, 20, and 21.

For arrays 7, 8, 9, 3, and 4, we found that nearly all steelhead tags that reached an array did so by day 7 or 8, with the exception of Release Group 1. Also, there was little difference in the timing of steelhead tags arriving at these arrays between the Groups 2 and 3. The first group showed the largest difference in arrival timing, with slower accumulation of steelhead tag detections; the reasons for this slower rate of accumulation are unknown.

For the array at the CVP facility (array 21), a similar pattern was observed with steelhead tags from Release Groups 2 and 3 reaching this location faster than Group 1 (Figure 5-3). However, for the array at the SWP Clifton Court Forebay radial gates (20), arrival timing was fastest during the more negative OMR flow conditions of Group 3. This result may be due to radial gate operations, with radial gates possibly being opened for longer durations or opened wider during Group 3 when pumping rates were highest. In either case, this appears to be a more localized effect of OMR flows influencing the arrival timing of steelhead tags that was not observed at arrays farther from the export facilities. At Chipps Island (array 24), steelhead tags from Group 2 reached array 24 before those of Groups 1 and 3, which were slower to exit the system and would have been exposed to predators for a longer time and may have reduced survival. Further, if travel time and exposure to predators govern survival, we would expect the highest survival in Group 2, which reached Chipps Islands faster (Figure 5-4 and Section 4.2.3). While we do not have individual survival estimates for the individual release groups (Section 4.2) we do provide evidence in Figure 4-4 to Figure 4-6 that the number of steelhead tags reaching Chipps Island was higher in Group 2 than in Groups 1 and 3.

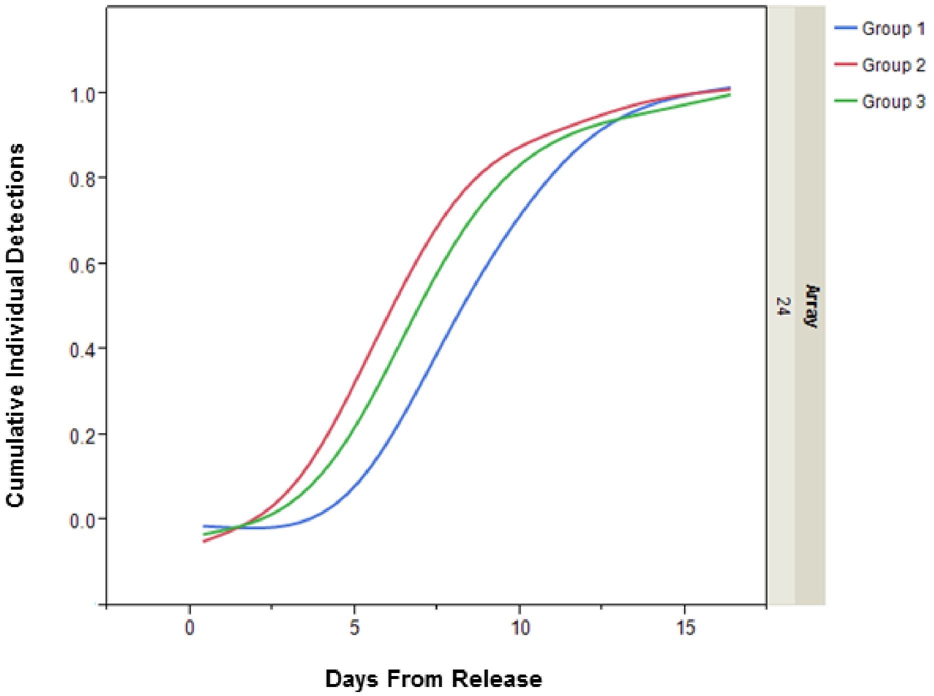


Figure 5-4 The cumulative detection curves for Groups 1, 2, and 3 at array 24.

In summary, OMR flows evaluated here appeared to have had little influence on steelhead tag movement during the study, except for limited evidence of an influence on steelhead tag routing at Railroad Cut in the interior Delta, and arrival timing at the SWP radial gates. Future studies should focus on how smolt movement and survival at Railroad Cut and southward (toward the export facilities) may be influenced by changing OMR flow conditions. In addition, future studies should be conducted under the entire range of possible OMR flow conditions to capture the range of possible effects on smolt movement and survival. As tidal conditions may also contribute to changes in fish behavior, any future studies should also be condcuted under shorter time periods with greater replication.

5.2 HOW EFFECTIVE WAS REAL-TIME MONITORING AND MANAGEMENT?

One of the project goals was to determine if real-time monitoring of steelhead smolt movement is feasible, and could it be conducted in a way to adaptively manage Delta exports to alter the routing and survival of steelhead in a timely and beneficial way. During the Stipulation Study, steelhead tags were used as “sentinels” to identify when wild salmonids were likely approaching the export facilities. Steelhead tag data were downloaded daily from the arrays near Railroad Cut (arrays 9 and 16) to track movement. When steelhead tag detections at Railroad Cut exceeded a threshold (5% of the release group detected at Railroad Cut; NMFS 2012), managers triggered a management option that reduced south Delta exports to provide additional protection for ESA-listed salmonids.

Given how quickly steelhead tags moved through the study system, most steelhead tags had already moved through the system before the triggered management option took effect. More than 90% of the steelhead tags had already left array 9 and passed by Railroad Cut before the effect of the management action was observed (OMR flows reached -1,250 cfs). Therefore, we cannot evaluate if reducing exports had the intended effect, given the small sample size of steelhead tags at Railroad Cut after the management action was implemented. While improvements to the experimental design of any future real-time monitoring study could be completed, this study points to the inability to effectively use tagged steelhead smolts as sentinels to trigger export changes. This study also provides evidence of the challenges of managing Delta flow conditions in real-time. Although the ability to manage flows is possible, the question of when and how to do this is not answered or supported from the data in this study.

In order to rapidly detect sentinel fish, receiver arrays would need to be downloaded more often than daily and ideally provide detections in real-time. True real-time detections would likely be necessary to be able to alter flow conditions quickly enough to influence fish movements. Even in real-time, monitoring stations may need to be placed farther north to allow the needed time for the presence of the focal species to be detected and the management option to be implemented and take effect before the majority of fish exit the area of influence.

The observed limited influence of OMR flows on steelhead tag behavior argues against the usefulness of real-time monitoring for protecting salmonids. Even if real-time monitoring could be conducted effectively, there is little evidence from this study to show that altering the OMR flow conditions would alter fish behavior in a meaningful way. We recommend that additional studies be conducted under a larger range of OMR flows to examine if and at what levels OMR flows affect the routing of steelhead. Flow conditions will need to be established for minimum time periods before changes are made as changing flow conditions during the study can limit the extent of analysis that can be performed.

5.3 WHAT WERE THE LIMITATIONS OF THE EXPERIMENTAL DESIGN AND HOW COULD THEY BE IMPROVED?

As with all field work and data analyses, this study faced some unforeseen challenges and complications. While no changes can guarantee that these do not occur in the future, these problems need to be identified so they can hopefully be avoided in future studies. In this section, we list and describe some examples.

Insufficient time to properly plan the study

This project was developed and implemented in a short time period that did not allow for certain important considerations to occur. The number of receivers, while extensive, was limited by the amount of time for acoustic receivers to be procured. Power analysis, which is useful in determining the proper sample size needed for an experiment, was not conducted as additional study fish were not available. Research requests for hatchery produced salmonids must be submitted several months in advance to allow for hatchery staff to produce the necessary study fish. Also, given the short amount of time for planning, careful consideration of the optimal placement of acoustic receivers to address the study hypotheses was not possible, limiting the conclusions that could be made from the resulting dataset.

Limited range of OMR flow conditions

One of the shortcomings of how the experiment was conducted was that the least negative on average OMR flow treatment was not met for Group 1. Therefore, given the data from this study, we could only examine how changes in OMR flows from -2,446 to -5,038 cfs affected steelhead tag movement and survival. As also evidenced by the results, a more negative OMR flow is needed to possibly measure any effect on fish movement.

Incompatibility and discrepancies of hydrodynamic datasets

Sub-daily (15-minute) hydrodynamic influences (proportional flow movement at junctions, average flow, percent positive flow) on fine-scale steelhead tag movement were expected to be analyzed to examine how tidal influences affect fish migration into the interior Delta, and patterns of migration behavior and survival once steelhead tags enter the interior Delta. However, as statistical analyses were being completed, we consistently observed steelhead tags moving opposite the direction of flow movement at the Turner Cut junction (the only junction analyzed in this way). These unexpected movement patterns were observed for steelhead smolts, suggesting these findings likely were not a true observation of fish behavior, but rather a spurious artifact of steelhead tag timing not being in-sync with available sub-daily DSM2 flow data used to inform flow conditions (Cavallo et al. 2012).

To examine if the steelhead tag and flow timing were out of sync, we compared DSM2 output near Turner Cut with observed flow data at gauging stations. Although the daily flow magnitude was similar between datasets, the tidal cycle appeared to be off-sync by approximately 2 hours. If the CDEC data represent the true flow conditions, then by analyzing DSM2 Hydro data at Turner Cut and other locations we may be relating steelhead tag behavior with incorrect flow conditions. Therefore, our findings of steelhead tags moving against flow movement were likely a result of steelhead tag timing being paired with flow conditions opposite of what they may have actually experienced. Rapid changes in tidal flow conditions mean that small discrepancies in timing between predicted and actual flow patterns can lead to results directly the opposite of expectations.

After completing the preliminary analyses, we also examined data from the few CDEC flow gauges with paired acoustic receiver arrays. For example, we examined steelhead tag arrival timing at array 9, near Railroad Cut, which is next to CDEC flow gauge MDM. We found that steelhead tags moved south toward Railroad Cut more often when OMR flows were positive (flows moving strongly north). This discrepancy indicated that there was two-dimensional hydrodynamic complexity of the Delta channels near Railroad Cut that were not being captured by the one-dimensional CDEC flow gauge. Although this is only a single location, this further exemplified the difficulty of examining fine-scale flow and steelhead tag relationships using the hydrodynamic data currently available. Because of the strong tidal influence in the Delta, flow measurements and steelhead tag observations must be paired perfectly together to know exactly what the flow conditions a steelhead tag was experiencing when making a routing "decision." Therefore, we did not examine fine-scale (less than 2-hour increments as seen in Section 4.3.2) tag and flow relationships for the analyses. For future studies, we recommend deploying flow measurement equipment specifically for these studies, and pairing them with acoustic receiver locations in order to reliably relate tag behavior and fine-scale flow conditions.

Inability to distinguish between a predator or tagged smolt

As stated in the assumptions section (Section 2.4), we were unable to identify a free-swimming tagged steelhead smolt from a tag that had been consumed by a predator. Therefore, we refer to detections as detections of steelhead tags throughout this report, rather than detections of acoustically tagged steelhead. The development of tags that can allow researchers to distinguish between smolts and predators is critical to ensure accurate filtering of free-swimming smolt data from steelhead tags that were consumed by predators.

Spatial resolution of acoustic telemetry and hydrodynamic data

The 2012 study utilized a one-dimensional array of receivers, which limited the fine-scale fish movement questions that could be answered. The one-dimensional array of receivers provided a simplification of the three-dimensional complexity of the interior Delta junctions and channels, limiting this investigation to one-dimensional movement patterns. To better understand steelhead smolt movement behavior, particularly at junctions, future studies will need to track the fine-scale movement of tagged smolts, paired with high resolution hydrodynamic data.

Low detection probabilities

Although overall most arrays had high detection probabilities (>80%), some sites (e.g., arrays 2 and 21) had lower probability of detections. Before future studies are conducted, we recommend that strategies be examined to raise detection probability. Possible strategies include: increasing the number of receivers deployed, optimizing their arrangement, and validating their effectiveness with empirical studies. Further, we recommend examining other types and providers of equipment to determine the best equipment for future studies. For example, we recommend that equipment such as Hydroacoustic Technology Inc. (HTI) and Juvenile Salmon Acoustic Telemetry System (JSATS) are considered for use in future studies.

Complexity of the system

The complexity of the south Delta limited our ability to adequately place arrays at many junctions and channels, making it difficult to meet the stringent assumptions needed for the USER model (Lady et al. 2008). For example, Columbia Cut is such a complex junction that even with optimal placement of arrays, it may not be possible to estimate separate survival and route entrainment probabilities in the USER models. If greater spatial resolution is required for future studies (e.g., more reach survival or more route entrainment calculations at junctions), additional receivers would need to be placed at strategic locations throughout the south Delta to ensure adequate coverage.

Limited sample size and statistical power

The relatively small sample sizes across release groups (166, 167, and 168 for Groups 1, 2, and 3, respectively) limited our ability to analyze the data. The total number of fish released across all release groups was similar to the number of Chinook salmon released in a single release group during the VAMP study (SJRGA 2013). The limited sample size contributed to the inability of the multistate model to converge on individual release group models, leading to a pooled model across release groups. Future studies should conduct power analyses prior to conducting the field study to ensure adequate sample size to address study questions.

5.4 WHAT FUTURE EXPERIMENTS AND METHODS ARE RECOMMENDED?

Meta-data analyses of past studies

Meta-analysis is an approach that gathers datasets from previous studies and analyzes them to see if there are important and robust relationships across the relevant studies. The Delta is well studied and therefore is the ideal study system for this type of approach using the datasets collected by the various agencies and groups: the California Department of Fish and Wildlife (CDFW), Department, East Bay Municipal Utilities District, NMFS, San Joaquin River Group Authority (SJRGA), Sacramento Municipal Waste Water Treatment Plant, Reclamation, USGS, USFWS, University of California at Davis, and others. Data from studies by these groups could be compared and evaluated immediately and with a limited budget, given that the project would not require additional money for field work. These studies require no new permits, which can be challenging and timeintensive to obtain. If this study is done, it would allow managers to know if results from one study or study period could be generalized to address other issues.

Similar study but more comprehensive with greater preparation, receiver coverage, larger sample size, more replication, and more extreme range of OMR flow values

Prior to any future experiment, careful deliberation of the experimental design and how resulting data will be analyzed would be crucial to providing more useful results. Primarily due to the extreme time limitations of the Stipulation Study, limited attention was given to determining an experimental design that could meet all project objectives. For example, only data from two of the Stipulation Study arrays were incorporated into the routing and survival model, causing us to rely on receivers from the Six-Year Study. This was due to limited consideration of how the study design would provide data required to answer study questions.

We recommend that future studies deploy additional receivers to provide better coverage of complex Delta junctions. Although expensive, it is easy to deploy receivers in numerous locations, thereby increasing the number of management questions that can be answered. However, the cost and location should be justifiable and add value to the study. For example, a central goal of this study was to quantify the routing and survival of steelhead. However, given the complexity of the system and assumptions of the modeling approach to conduct the analyses, we were only able to estimate routing at Turner Cut (arrays 1, 2, and 7). At other junctions, we did not feel there was enough coverage of receiver arrays to meet the assumptions of the modeling program USER so that it could estimate separate route entrainment and survival probabilities for each route. These receivers must be placed just upstream of the junction and closely downstream after the junction so that there is no overlap in the detection coverage of the receivers. For more information on this topic, see Chapter 2 of the doctoral thesis by Perry (2010).

For any future experiment, sufficient sample sizes of tagged fish should be released to provide the necessary statistical power to examine the hypotheses of interest. Small sample sizes during this study limited our ability to examine routing and survival differences between treatment groups. Therefore, before any future experiments are conducted, power analyses should be completed to determine the sample sizes needed to find significant differences.

We propose that a future experiment would only be useful and better to analyze if it were done with larger differences in OMR flow conditions and that treatment levels are replicated. Therefore, rather than implementing each OMR flow treatment only once, it would be best to replicate each of the treatments at least twice, if not more. This form of replication should be done over multiple years to examine inter-annual variability and the applicability of the results and relationships to other situations. Also, we recommend that the range of OMR flows examined be at least as extreme as initially planned for in this experiment (-1,250, -3,500, and -5,000 cfs), which was not met in the actual experiment. Preferably, we recommend replicated experiments that are conducted over a wider range of OMR flows, possibly differing by an order of magnitude or more (e.g., -1,000 to -10,000 or 1,500 to -15,000 cfs).

It is critical that the design and implementation of this experiment be given sufficient time. The design and implementation of any future study should not be conducted in 2 months but should be given the proper time and money for this critical stage to be deliberate, methodical, and not rushed. Sufficient time should be given to carefully consider the placement of acoustic receiver arrays to make sure that all study hypotheses can be properly examined. Time is also needed to conduct power analyses to determine proper sample sizes in order to detect differences in subsequent statistical tests. Sufficient time is also needed to identify and provide the essential field resources to implement increased sample sizes and additional receiver arrays.

Examining model design and selection and the effect on estimated parameters

We recommend that an analysis be conducted on how model design affects the parameter estimates generated by the multistate statistical release-recapture model. The choices of what arrays are used, how many are used, and where they are positioned could affect survival or route entrainment estimates. For this study we allowed the model to fit all parameter values without making post-hoc adjustments to values to improve model fit. We did not change or set anything in the model that was not a priori determined except for replacing array 6 with 7 and pooling release group data due to lack of model convergence. For example, we could have adjusted the detection probabilities fit by the model by using our Manly-Parr detection probability estimates at dual arrays and then re-run the model. Because these model design decisions may have an impact on model outcomes, we recommend examining the consequences of these decisions in a future study. The dataset from this study could be an ideal example for this type of analysis.

Improvement of current models or creating new and more accurate models

The DSM2 Hydro PTM model underestimated the speed with which steelhead tags were migrating and inaccurately predicted their final location 7 days following release. Therefore, in its current form, the DSM2 Hydro PTM model did not appear to be a reliable model for simulating the movement patterns of steelhead tags. This result is important for management of this species as the DSM2 Hydro PTM model has been used in the past to manage for steelhead by examining the effect of various types of barriers and entrainment into various structures (e.g., agricultural diversion or export facilities). Therefore, we recommend that further study be conducted to better understand what causes the model to underestimate the speed of steelhead tags and inaccurately predict their locations and that future particle model runs incorporate specific fish movement behavior to better predict fish movement patterns. Important fish behaviors have yet to be identified and quantified. Until this step is taken, a coupled biological-physical model cannot be produced to accurately predict the speed of steelhead and other behaviors that are important for managing the species of concern or the operations of the SWP and CVP.

Experimental operation of export facilities

By conducting experimental operations of the export facilities, key questions could be answered about how exports influence the behavior and survival of salmonid smolts. To isolate the effect of each export facility (SWP and CVP) on fish behavior and survival, all exports could be shifted to either facility for a brief period of time during future biotelemetry studies. Eliminating exports completely during an experimental study (e.g., if both facilities have maintenance during the same period of time), along with examining the extreme high end of exports (as recommended above), would allow for an evaluation of the complete range of export effects.

Fine-scale and tidal experiments

While large-scale studies are useful, the large spatial scale and complexity of the environment being examined commonly result in study findings that are coarse and limited in their ability to answer fine-scale questions. Smaller scale experiments can provide higher resolution fish and environmental data more easily, and provide higher accuracy results. Conducting fine-scale experiments using two- or three-dimensional acoustic receiver arrays paired with fine-scale hydrodynamic data collected simultaneous with fish releases could help answer a multitude of questions. One sample experiment we recommend would examine fish routing and survival in the interior Delta near Railroad Cut. While we conducted an exploratory analysis examining routing at Railroad Cut (described in Section 4.3.3), we could only coarsely examine how broad movement patterns were affected across the narrow range of OMR flows examined. Greater receiver coverage and multi-dimensional tracking, paired with fine-scale hydrodynamic data and locally released smolts, would provide high resolution information on how fish move at this critical junction and what factors influence routing and survival in the interior Delta. While it could be argued that such a fine-scale study would only provide site-specific information, a better understanding of the mechanisms underlying fish routing and survival could be gained, to better understand steelhead smolt behavior at the junctions examined.

Although we examined if STST fish behavior occurred in a short reach in the interior Delta, a greater understanding of how steelhead smolts use the tides during migration is critical to understanding how best to manage the Delta (Kneib et al. 2012). Many questions remain about how steelhead smolts use the tides for movement, including:

- Do steelhead use ebb tides equally for migration, or do they only "surf" tides during the daytime or nighttime?
- Do other factors influence how steelhead smolts use tides, such as habitat quality or predation?
- What level of tidal influence is needed for steelhead smolts to exhibit STST behavior?
- How does STST behavior vary spatially across the Delta?

We recommend conducting fine-scale smolt tagging studies across the Delta, while simultaneously collecting hydrodynamic data, to better understand how tides influence steelhead smolt movement, survival, and travel time. Releases of tagged fish could occur at various tidal stages (e.g., flood and ebb tides). Given that the tidal stage changes throughout the day, and the amplitudes of tides change multiple times in a lunar month, experiments could be conducted frequently and in short durations. Therefore, study replication would be easy to accomplish, which is key for any well-designed experiment.

Predation tags

A prototype acoustic tag has been developed that would distinguish between smolts and predators. This prototype tag is currently being tested by the Department and Reclamation. If the prototype is successful, all future tagging studies should use these new tags or similarly tested and successful tags to more accurately filter predators from the data set and provide more accurate data on tagged smolt movement and survival.

Additional management trigger studies

While the Stipulation Study attempted to use real-time monitoring of tagged hatchery steelhead to limit the entrainment of wild steelhead smolts at the export facilities, the experiment was largely unsuccessful. Most of the tagged steelhead had already passed Railroad Cut before the effect of the flow trigger was observed (OMR flows reached -1,250 cfs), thereby limiting the influence of triggered flow conditions on steelhead tag movement. It is unknown how well tagged hatchery steelhead provided a proxy for wild steelhead. If additional studies are warranted, we recommend that an experimental approach be first conducted that uses true "real-time" remote monitoring of receivers and examine multiple receiver locations to determine the location of where real-timing monitoring arrays would be most effective. In addition, a wider range and minimum duration of flow management alternatives should be examined to better understand if a real-time flow trigger can provide any benefit to steelhead smolt survival. Finally, the feasibility of using wild steelhead smolts during future real-time flow trigger experiments should be examined to more directly attempt to understand wild steelhead smolt movement in the Delta.

5.5 CONCLUSIONS

- Overall, under the OMR flows tested and the conditions that occurred during the field study, there was little influence of OMR flows on steelhead tag movement during the study.
- This study was limited by the amount of time for its preparation and the ranges of OMR flows tested. Future studies should be performed with adequate preparation time and with more control over the OMR flow ranges, including OMR flows beyond those allowed by both health and safety standards and by water quality and ESA protections.
- There was limited evidence of OMR flows influencing steelhead tag routing at Railroad Cut in the interior Delta and arrival timing at the SWP Clifton Court Forebay radial gates.

- The quantitative statistical analyses determined that the DSM2 Hydro PTM was not able to predict the movement of steelhead tags because it greatly underestimated steelhead tag movement through the study area.

- There was evidence that diurnal and nocturnal movement patterns of steelhead tags might be occurring, but these patterns were location-specific. Future study is needed to understand this pattern.

- There was limited evidence that altering OMR flow conditions tested within the levels observed in the study would alter fish behavior in a meaningful way. Future studies should be performed with a wider range of OMR flows and of minimum duration to provide evidence that real-time monitoring could be used to protect salmonids.

- Future studies should focus on how steelhead smolt movement and survival at Railroad Cut and south (toward the export facilities) may be influenced by a wider range of OMR flow conditions and minimum duration than examined in this study.

- Future studies, including a more comprehensive version of this experiment should be conducted with a wider range of OMR flows and of minimum duration that are replicated with more acoustic receivers and larger sample size of tagged fish.

This page intentionally left blank.

6 REFERENCES

Anderson, J. J., E. Gurarie, and R. W. Zabel. 2005. Mean free-path length theory of predator-prey interactions: Application to juvenile salmon migration. Ecological Modelling 186:196-211.

Bégout Anras, M. L., and J. P. Lagardere. 2004. Measuring cultured fish swimming behavior: first results on rainbow trout using acoustic telemetry in tanks. *Aquaculture* 240, 175-186.

Buchanan, R. A. 2013. Juvenile Salmonid Survival Through the San Joaquin Delta in the Presence of Predatory Fish, 2010-2011. PowerPoint presentation prepared by Rebecca Buchanan, Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, Seattle. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=69586. Accessed November 2013.

Buchanan, R. A., and R. Perry. 2011. Survival Analysis of Tagging Data. PowerPoint presentation by R. Buchanan, University of Washington, and R. Perry, U.S. Geological Survey, June 28-29, 2011.

Buchanan, R. A., J. R. Skalski, P. L. Brandes, and A. Fuller. 2013. Route use and survival of juvenile Chinook salmon through the San Joaquin River Delta. *North American Journal of Fisheries Management* 33:1, 216-229.

California Data Exchange Center (CDEC). 2013. Department of Water Resources, CDEC data for the Turner Cut Near Holt Station. Available at: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=TRN. Last accessed on October 15, 2013.

Cavallo, B., P. Bergman, J. Melgo, K. Jones, and P. Gaskill. 2012. Status Report for 2012 Acoustic Telemetry Stipulation Study. Series: Cramer Fish Sciences, 30 pages. Available at: http://deltacouncil.ca.gov/sites/default/files/documents/files/20121015_STIP_Status_Report.pdf. Last accessed on October 15, 2012.

Chapman, E. D., A. R. Hearn, C. J. Michel, A. J. Ammann, S. T. Lindley, M. J. Thomas, P. T. Sandstrom, G. P. Singer, M. L. Peterson, R. B. MacFarlane, A. P. Klimley. 2013. Diel movements of out-migrating Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) smolts in the Sacramento/San Joaquin Watershed. *Environmental Biology of Fishes* 96:273–286.

Chittenden, C. M., S. Sura, K. G. Butterworth, K. F. Cubitt, N. Plantalech Manel-La, S. Balfry, F. Ǿkland, and R. S. McKinley. 2008. Riverine, estuarine and marine migratory behavior and physiology of wild and hatchery-reared coho salmon Oncorhynchus kisutch (Walbaum) smolts descending the Campbell River, BC, Canada. Journal of Fish Biology 72:614-628.

Clark, K. W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson. 2009. Quantification of Pre-Screen Loss of Juvenile Steelhead in Clifton Court Forebay. State of California, California Department of Water Resources, Sacramento, California.

Clements, S., T. Stahl, and C. B. Schreck. 2012. A comparison of the behavior and survival of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout *(O. mykiss*) in a small estuary system. *Aquaculture* 362-363:148-157.

Cramer Fish Sciences. 2013. Phase II Data Analysis Plan for the 2012 Acoustic Telemetry Stipulation Study. Prepared by David Delaney, Paul Bergman, Brad Cavallo, and Jenny Melgo, Cramer Fish Sciences, under the direction of Kevin Clark, California Department of Water Resources.

Delaney, D. G., P. Edwards, and B. Leung. 2012. Predicting regional spread of invasive species using oceanographic models – validation and identification of gaps. *Marine Biology* 2:269-282.

Drenner, S. M., T. D. Clark, C. K. Whitney, E. G. Martins, S. J. Cooke, and S. G. Hinch. 2012. A synthesis of tagging studies examining the behavior and survival of anadromous salmonids in marine environments. PLoS ONE 7(3): e31311. Doi: 10.1371/journal.pone.0031311.

Fox, J. 2005. The R Commander: A Basic Statistics Graphical User Interface to R. Journal of Statistical Software, 14(9): 1-42.

Gingras, M. 1997. Mark/recapture experiments at Clifton Court Forebay to estimate pre-screening losses to juvenile fishes 1976–1993. *Interagency Ecological Program Technical Report 55*.

Kahle, D., and H. Wickham. 2013. ggmap: A package for spatial visualization with Google Maps and OpenStreetMap. R package version 2.3. Available at: http://CRAN.R-project.org/package=ggmap. Last accessed on December 10, 2013.

Kimmerer, W. J., and M. L. Nobriga. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. *San Francisco Estuary and Watershed Science* Vol. 6, Issue 1 (February), Article 4:1-26. Available at: http://repositories.cdlib.org/jmie/sfews/vol6/iss1/art4/. Last accessed on October 15, 2013.

Kneib, R. T., J. J. Anderson, A. Gore, M. S. Lorang, J. M. Nestler, and J. Van Sickle. 2012. Report of the 2012 Delta Science Program Independent Review Panel (IRP) on the Long-term Operations Opinions (LOO) Annual Review. Available at: http://nodeltagates.files.wordpress.com/2012/12/isb_report_2012_dspirp_looar_120112_final.pdf. Last accessed on December 15, 2012.

Lady, J. M., P. Westhagen, and J. R. Skalski. 2008. USER 4: User specified estimation routine. School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. Available at: http://www.cbr.washington.edu/paramest/user/. Last accessed on October 15, 2013.

Manly, B. F. J., and M. J. Parr. 1968. A new method of estimating population size, survivorship, and birthrate from capture–recapture data. *Transactions of the Society for British Entomology* 18:81-89.

Martin, F., R. D. Hedger, J. J. Dodson, L. Fernandes, D., Hatin, F. Caron, and F. G. Whoriskey. 2009. Behavioural transition during the estuarine migration of wild Atlantic salmon (*Salmo salar* L.) smolt. *Ecology of Freshwater Fish* 18:406-417.

Melnychuk, M. C., D. W. Welch, and C. J. Walters. 2010. Spatio-temporal migration patterns of Pacific salmon smolts in rivers and coastal marine waters. PLoS ONE 5(9): e12916. Doi: 10.1371/journal.pone.0012916.

Metaxas, A., and M. Saunders. 2009. Quantifying the ‘‘Bio-’’ components in biophysical models of larval transport in marine benthic invertebrates: advances and pitfalls. *Biological Bulletin* 216:257-272.

Moore, A., E. C. E. Potter, N. J. Milner, and S. Bamber. 1995. The migratory behavior of wild Atlantic salmon (*Salmo salar*) smolts in the estuary of the River Conwy, North Wales. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1923-1935.

National Marine Fisheries Service (NMFS). 2009 (June 4). *Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project*. Southwest Regional Office, Long Beach, California.

National Marine Fisheries Service (NMFS). 2012. Technical memorandum to guide adaptive management of OMR during April and May 2012 for the protection of listed San Joaquin Basin steelhead. Southwest Regional Office, Long Beach, California.

Perry, R. W. 2010. Survival and migration dynamics of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin River Delta. Dissertation, University of Washington.

Perry, R. W., J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River Delta. *North American Journal of Fisheries Management* 30:142-156.

R Project. 2013. The R Project for Statistical Computing. Available at: http://www.r-project.org/. Last accessed on October 15, 2013.

RStudio Inc. 2013. Shiny: Web Application Framework for R. R package version 0.8.0. Available at: http://CRAN.R-project.org/package=shiny. Last accessed on December 10, 2013.

San Joaquin River Group Authority (SJRGA). 2011. 2010 Annual technical report on implementation and monitoring of the San Joaquin River agreement and the Vernalis Adaptive Management Plan (VAMP).

San Joaquin River Group Authority (SJRGA). 2013. 2011 Annual technical report on implementation and monitoring of the San Joaquin River agreement and the Vernalis Adaptive Management Plan (VAMP).

This page intentionally left blank.

APPENDIX A

Concordance Table

Concordance table that covers how the objectives and hypotheses have changed, adapted, or stayed the same during the different stages of the study.

Concordance Table						
	Objective			Hypothesis		
Version	**Number**	**Description**	**Changes from Previous**	**Number**	**Description**	**Changes from Previous**
December 6, 2012	1	What factors influence route entrainment into the interior Delta from Turner Cut, Colombia Cut and Middle River?	N/A	1.1	The proportion of tagged fish entering the interior Delta route is not related to release group, study, junction, and time-at-large.	N/A
	2		N/A	2.1	The probability of fish returning to Mainstem SJR is not related to release group, study, junction and time-at-large.	N/A
				2.2	Residence time of fish in Delta reaches (between arrays) does not vary by release group, study, or time-at-large.	N/A
				2.3	The movement of fish in the Mainstem and in the interior Delta will be random (i.e., not related to tidal periodicity).	N/A
	3		N/A	3.1	The survival of tagged fish in the interior Delta is not different from the survival in the San Joaquin River.	N/A
				3.2	Survival through the Mainstem San Joaquin River is not significantly related to study or release group.	N/A
				3.3	Survival through the interior Delta is not significantly related to study or release group.	N/A
				3.4	Routing through the interior Delta does not differ with group or study.	N/A

Concordance Table

	Objective			Hypothesis		
Version	**Number**	**Description**	**Changes from Previous**	**Number**	**Description**	**Changes from Previous**
February 11, 2013	1	How do group and study influence survival and routing?	Same as previous Objective 3.	1.1	Overall Delta survival and route survivals were not significantly related to study or release group.	Same as previous 3.2 and 3.3 combined.
				1.2	The survival of tagged fish in the interior Delta is not different from the survival in the San Joaquin River.	Same as previous 3.1.
				1.3	Routing at each junction (Turner Cut, Columbia/Middle, Railroad Cut) did not differ with group, study, or due to export trigger.	Same as previous 3.4 and 1.1 combined. Also, added in an examination of export trigger on routing.
	2	What factors influenced fine-scale migration behavior in the interior Delta?	Same as previous Objective 2.	2.1	The proportion of fish returning to Mainstem SJR was not related to release group, study, or junction.	Same as previous 2.1.
				2.2	The movement of fish in the Mainstem and interior Delta is random (i.e., not related to tidal periodicity or day/night).	Includes previous 2.3 examination of tidal periodicity and also new examination of diurnal effect.
				2.3	The last location of acoustically tagged fish was not significantly different than the last location of modeled particles.	New hypothesis.
				2.4	Routing through the interior Delta does not differ with group or study.	New hypothesis.

Concordance Table

	Objective			Hypothesis		
Version	**Number**	**Description**	**Changes from Previous**	**Number**	**Description**	**Changes from Previous**
March 29, 2013	1	To examine if survival and routing probabilities vary between different release groups.	Same as previous Objective 1.	1.1	Overall Delta survival and route survivals were not significantly related to study or release group.	Same as previous 1.1.
				1.2	The survival of tagged fish in the interior Delta is not different from the survival in the San Joaquin River.	Same as previous 1.2.
				1.3	Survival to Chipps Island was not significantly different for tags going through salvage versus tags that did not go through salvage.	New hypothesis.
				1.4	Routing at Turner Cut did not differ with release group or study.	Similar to previous 1.3 except only examining Turner Cut junction. The other junctions are examined in the new 2.1.
	2	What factors influenced within-reach migration behavior in the interior Delta?	Same as previous Objective 2.	2.1	The proportion of tags that entered the interior Delta at Columbia Cut or Middle River was not related to release group.	Similar to previous 1.3 but only examines Columbia and Middle Junctions. Turner Cut is in new 1.4 and Railroad Cut is new 2.6.
				2.2	The movement of fish in the Mainstem and interior Delta is random (i.e., not related to day/night).	Examines diurnal effect on tag movement as in previous 2.2, but tidal effects are now examined differently in new 2.3.
				2.3	The acoustically tagged fish did not move using STST.	New hypothesis.
				2.4	The last location (receiver array) of tags was not significantly different than the last location of modeled particles.	Same as previous 2.3.
				2.5	The migration rate of tags was not significantly different between fish routes or between release groups.	New hypothesis.
				2.6	The movement patterns of tags after Railroad Cut were not different before and after the OMR trigger.	Previously part of hypothesis 1.3.

Concordance Table

	Objective			Hypothesis		
Version	**Number**	**Description**	**Changes from Previous**	**Number**	**Description**	**Changes from Previous**
Data Analysis Plan (June 28, 2013)	1	To examine if survival and routing probabilities vary between different release groups.	Same as previous Objective 1.	1.1	Overall survival and route-specific transitions probabilities of tags were not significantly related to release group.	Same as previous 1.1.
				1.2	The survival of tagged fish in the interior Delta is not different from the survival in the San Joaquin River.	Same as previous 1.2.
				1.3	Routing at Turner Cut did not differ with release group or study.	Same as previous 1.4.
	2	What factors influenced reach-specific survival and routing in the interior Delta?	Same as previous Objective 2.	2.1	The proportion of tags that entered the interior Delta at Columbia Cut or Middle River was not related to release group.	Same as previous 2.1.
				2.2	The movement of fish in the Mainstem and interior Delta is random (i.e., not related to day/night).	Same as previous 2.2.
				2.3	The acoustically tagged fish did not move using STST.	Same as previous 2.3.
				2.4	The last location (receiver array) of tags was not significantly different than the last location of modeled particles.	Same as previous 2.4.
				2.5	The travel times of acoustically tagged fish were not significantly different between routes or between release groups.	Similar to previous 2.5 except examining travel time instead of migration rate.
				2.6	The movement patterns of tags after Railroad Cut were not different before and after the OMR trigger.	Same as previous 2.5.
				2.7	The daily proportion of tags at each of the export facilities is proportional to the fraction of the water entering the facilities.	New hypothesis.

Concordance Table

	Objective			Hypothesis		
Version	**Number**	**Description**	**Changes from Previous**	**Number**	**Description**	**Changes from Previous**
Final Report (February 3, 2014)	4.1	**System**: Examine large-scale movement patterns of steelhead tags.	Comprises hypotheses from previous objective 2 that examine system-wide processes affecting tag movement and includes new descriptive analyses.	4.1.1	Examined the spatial pattern of steelhead tags detected at each array by release group.	New descriptive analysis without a predetermined hypothesis.
				4.1.2	Examined the spatial pattern of where steelhead tags were last detected by release group.	New descriptive analysis without a predetermined hypothesis.
				4.1.3	Examined the spatial pattern of residence time at each array by release group.	New descriptive analysis without a predetermined hypothesis.
				4.1.4	Examined the spatial pattern of the final fate of tags at each array by release group.	New descriptive analysis without a predetermined hypothesis.
				4.1.5	Created a web-based dissemination tool to spatially display the full detection history of individual tags.	New descriptive analysis without a predetermined hypothesis.
				4.1.6	The distance traveled by steelhead tags was not significantly different than the distance traveled by the passive particles.	Similar to the previous 2.4 except we reworded for clarity.
				4.1.7	Steelhead tags did not move using STST.	Similar to the previous 2.3 except we removed reference to fish.
				4.1.8	The movement of steelhead tags in the San Joaquin River and interior Delta was not related to day/night.	Similar to the previous 2.2 except we removed reference to fish.
	4.2	**Route**: Examine how steelhead tags move through the system using different defined routes.	Comprises previous Objective 1 and route-specific hypothesis from previous Objective 2.	4.2.1	Route-specific transition probabilities of steelhead tags were not significantly related to the route taken and/or release group.	Similar to previous 1.1 except release-specific models would not converge to examine release-specific survival. Also, overall survival was moved to Hypothesis 4.2.2.
				4.2.2	The estimated route-specific survival for the Turner Cut route was not significantly different from the Mainstem route.	Similar to the previous 1.2 except we deleted the reference to fish.

Concordance Table

	Objective			Hypothesis		
Version	**Number**	**Description**	**Changes from Previous**	**Number**	**Description**	**Changes from Previous**
				4.2.3	The travel times of steelhead tags were not significantly different between routes or release groups.	Same as previous 2.5 except we deleted the reference to fish.
	4.3	**Junction**: Examine how steelhead tags move through junctions.	Comprises hypotheses from previous Objective 2 that examine junction-specific analyses.	4.3.1	The probability of steelhead tags entering the interior Delta at Turner Cut, Columbia Cut, and Middle River was not related to OMR flows.	Combines previous 1.3 and 2.1 and is the same except we deleted the reference to fish.
				4.3.2	Steelhead tag arrival at each facility was not related to the proportion of total export flow entering SWP.	Similar to previous 2.7 except we are working with 2-hour data and array level data that allows us to use finer temporal data.
				4.3.3	The movement patterns of steelhead tags after passing through Railroad Cut were not affected by OMR flows.	Same as previous 2.6 except we changed how we refer to tags.

APPENDIX B

Crosswalk Table of Tag and Dependent Analysis

Note: This appendix presents the data used to produce the figures and results for the analyses in this report (Chapter 4). If data from a steelhead tag were used in the figure and/or analysis for that section, a "1" was placed in that cell. For Section 4.1.6, we presented the data for tags that were detected on the third ("4.1.6 [3D]") and seventh day ("4.1.6 [7D]") after their release. For Section 4.3.1, we examined three junctions: Turner Cut ("4.3.1 [TC]"), Columbia Cut ("4.3.1 [CC]"), and Middle River ("4.3.1 [MR]")

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133669	1	1			1	1		1	1		1	1
1133670	1	1			1	1		1				1
1133671	1	1			1	1		1	1	1		
1133672	1		1		1	1		1	1	1		
1133673	1		1		1	1		1	1			
1133674												
1133675												
1133677	1	1	1		1	1						
1133678	1	1		1	1	1		1				1
1133679	1	1		1	1	1	1	1				
1133680	1				1	1		1				
1133681	1	1	1		1	1	1	1	1	1		
1133682	1	1			1	1		1				
1133683	1		1	1	1	1		1			1	
1133684	1	1	1		1	1		1	1			
1133685	1				1	1		1				
1133686	1	1			1	1		1	1	1	1	1
1133687	1	1	1		1	1						
1133688	1	1			1	1		1	1			
1133689	1	1			1	1						
1133691	1	1	1	1	1	1		1				
1133692	1	1	1	1	1	1		1				1
1133693	1	1		1	1	1		1				1
1133694	1	1	1		1	1	1	1	1			
1133695	1	1	1		1	1		1			1	1
1133696	1		1	1	1	1		1				
1133697	1	1		1	1	1		1				1
1133698	1	1	1	1	1	1		1	1		1	1
1133699	1	1			1	1		1				
1133700	1	1	1		1	1	1	1				
1133701	1			1	1	1		1				
1133702	1		1		1	1		1				

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133703	1				1	1		1				
1133704	1				1	1		1	1	1		
1133705	1				1	1		1				
1133706	1				1	1						
1133707	1				1	1						
1133708	1	1	1		1	1		1	1			
1133709												
1133710	1	1	1		1	1						
1133711	1	1	1		1	1		1				
1133712	1	1		1	1	1	1	1				1
1133713	1	1			1	1		1				
1133714	1		1		1	1	1	1	1	1		
1133715	1	1			1	1		1	1			
1133716	1				1	1		1	1	1		
1133717	1				1	1						
1133718	1	1			1	1		1	1	1		
1133719	1	1			1	1						
1133720	1	1	1		1	1		1	1			
1133721	1	1	1		1	1		1	1	1		1
1133722												
1133723	1	1			1	1						
1133724												
1133725	1	1	1	1	1	1	1	1				1
1133726	1	1			1	1		1	1			
1133727	1	1			1	1		1				
1133728	1	1	1		1	1		1	1	1	1	1
1133729	1				1	1		1				
1133730	1		1		1	1	1	1	1	1		
1133731	1	1	1		1	1	1	1	1	1		
1133732	1			1	1	1		1				
1133733	1	1	1	1	1	1		1				1
1133734	1	1		1	1	1		1				

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133735	1		1		1	1		1	1	1		
1133736												
1133737	1	1	1		1	1		1	1			
1133738	1		1		1	1						
1133740	1	1			1	1		1	1			
1133741												
1133742	1	1	1		1	1		1				
1133743												
1133744	1	1	1		1	1	1	1	1			
1133745	1			1	1	1		1				
1133746	1	1	1		1	1	1	1	1	1		
1133747	1		1		1	1		1				
1133748	1	1	1		1	1		1	1		1	1
1133749	1		1		1	1		1	1	1		
1133750	1	1	1	1	1	1		1				1
1133751	1	1		1	1	1		1				
1133752	1				1	1						
1133753	1	1	1	1	1	1		1				
1133754	1				1	1		1				
1133755	1	1	1		1	1	1	1	1	1		
1133756												
1133757												
1133758	1		1		1	1		1				
1133759	1	1	1		1	1		1	1	1		
1133760	1	1			1	1		1	1			
1133761	1		1		1	1	1	1	1	1		
1133762	1	1	1		1	1	1	1	1	1		
1133763												
1133764	1			1	1	1		1				
1133765	1	1	1		1	1		1	1	1		1
1133766	1		1		1	1						
1133767	1				1	1		1				

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133768	1				1	1		1				
1133769	1	1		1	1	1		1				
1133770	1	1	1	1	1	1		1				
1133771	1				1	1						
1133772	1		1	1	1	1		1				
1133773	1				1	1	1	1	1	1		
1133774	1	1		1	1	1		1			1	1
1133775	1	1	1		1	1	1	1	1	1		
1133776	1				1	1						
1133777	1	1	1	1	1	1		1				1
1133778	1		1	1	1	1		1				1
1133779	1	1	1		1	1		1	1	1		
1133780	1			1	1	1		1				
1133782	1			1	1	1		1				1
1133783	1	1			1	1		1	1			1
1133784	1	1			1	1		1				
1133785	1				1	1						
1133786	1			1	1	1		1				
1133787	1				1	1		1	1			
1133788	1	1			1	1		1				
1133790	1				1	1		1				
1133791	1	1	1	1	1	1		1			1	1
1133792	1	1	1	1	1	1		1			1	1
1133793	1	1	1		1	1		1	1	1		
1133794	1		1	1	1	1		1			1	
1133795	1			1	1	1		1				1
1133796	1	1	1	1	1	1		1				
1133797												
1133798	1		1		1					1		
1133799	1	1			1	1		1	1	1		
1133800	1		1		1	1		1	1	1		
1133801	1	1		1	1	1		1				

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133802	1			1	1	1		1				1
1133803	1	1			1	1		1				
1133804	1	1	1	1	1	1	1	1				
1133805	1	1	1		1	1	1	1				1
1133806	1	1			1	1	1	1	1	1		
1133807	1	1			1	1	1	1	1	1		
1133808	1	1			1	1		1				
1133809	1		1		1	1		1	1	1		
1133810	1	1			1	1		1				
1133811												
1133812	1			1	1	1		1				
1133813	1				1	1		1	1			
1133814	1	1			1	1		1	1	1		
1133815	1	1	1		1	1		1				
1133816												
1133817	1	1	1		1	1		1	1			
1133818	1				1	1						
1133819	1	1	1		1	1		1				1
1133820	1	1	1	1	1	1		1				
1133821	1	1	1		1	1		1	1	1	1	1
1133822	1				1	1						
1133823	1	1			1	1		1	1	1		
1133824	1	1	1		1	1	1	1	1	1		
1133825	1		1		1				1	1		
1133826	1	1		1	1	1		1				
1133827	1		1	1	1	1	1	1				
1133828	1	1			1	1		1	1			
1133829	1		1		1	1		1	1			
1133830	1	1	1	1	1	1		1				
1133831	1	1	1	1	1	1		1			1	
1133832	1				1							
1133833	1				1	1						

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133834												
1133835	1		1		1	1		1	1			
1133836												
1133837	1	1		1	1	1		1				
1133838	1	1	1		1	1	1	1	1	1		
1133839	1		1		1	1	1	1				
1133840	1				1	1		1	1			
1133841	1				1	1		1	1	1		
1133842	1				1	1		1				
1133843	1			1	1	1		1				1
1133844	1				1	1		1	1			
1133845	1	1			1	1	1	1	1	1		
1133846	1				1	1						
1133847	1				1	1		1				
1133848	1	1			1	1	1	1	1	1		
1133849	1	1	1	1	1	1		1				1
1133850	1	1		1	1	1		1				
1133852	1	1			1	1	1	1	1	1		
1133853	1				1					1		
1133854	1	1		1	1	1		1				1
1133855	1	1			1	1		1	1	1		
1133856	1	1			1	1		1	1			
1133857	1				1	1		1				
1133858	1				1	1						
1133859	1	1	1		1	1	1	1	1			
1133860	1		1	1	1	1	1	1				
1133861	1	1			1	1		1	1			
1133862	1	1			1	1		1	1	1		
1133863	1				1	1		1	1			
1133864	1	1	1		1	1		1	1	1		
1133865	1				1	1	1	1	1	1		
1133866	1	1	1		1	1	1	1	1	1		

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133867	1	1			1	1		1	1		1	1
1133868	1	1		1	1	1		1				
1133869	1	1			1	1	1	1	1	1		
1133870	1	1	1	1	1	1		1			1	1
1133871	1	1			1	1		1				
1133872	1	1	1	1	1	1		1			1	1
1133873												
1133874	1	1		1	1	1		1				
1133875	1			1	1	1		1			1	1
1133876												
1133877	1	1	1	1	1	1		1			1	1
1133878	1	1	1		1	1	1	1	1	1		
1133879	1			1	1	1		1				
1133880	1	1		1	1	1	1	1				
1133881												
1133882	1	1			1	1						
1133883	1	1			1	1		1				
1133884	1			1	1	1		1				
1133885	1				1	1		1	1	1		
1133886	1	1		1	1	1		1				
1133887	1	1	1		1	1	1	1	1	1		
1133888	1		1		1	1		1	1			
1133889	1	1			1	1		1				
1133890	1				1	1		1	1	1		
1133891	1	1			1	1		1	1	1		
1133892	1	1		1	1	1		1				
1133893	1	1	1	1	1	1		1				
1133894	1				1	1	1	1	1			
1133895	1	1	1		1	1		1	1	1		
1133896	1	1		1	1	1		1				1
1133897	1				1	1		1	1	1		
1133898	1				1	1		1	1	1		

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133899	1	1			1	1		1	1	1		
1133900	1	1	1		1	1		1	1			
1133901												
1133902	1	1		1	1	1		1			1	
1133903	1		1	1	1	1		1				1
1133904	1	1		1	1	1		1			1	1
1133905	1			1	1	1		1				
1133906	1	1			1	1		1			1	1
1133907	1		1		1	1	1	1	1			
1133908	1		1		1	1	1	1	1	1		
1133909	1	1		1	1	1		1			1	1
1133910	1	1		1	1	1		1				1
1133911												
1133912	1				1	1		1	1	1		
1133913	1	1			1	1		1	1	1		
1133914	1	1			1	1		1	1	1		
1133915	1	1			1	1	1	1	1	1		
1133916	1				1	1		1	1			
1133917	1		1		1	1		1	1		1	1
1133918	1			1	1	1		1				
1133919	1	1			1	1	1	1	1	1		
1133920	1	1			1	1	1	1	1			
1133921												
1133922	1	1			1	1		1	1			
1133923	1	1			1	1	1	1	1	1		
1133924	1	1		1	1	1		1				
1133925	1	1			1	1		1	1	1		
1133926	1	1	1		1	1		1			1	
1133927	1	1		1	1	1	1	1				
1133928	1		1		1	1						
1133929	1		1		1	1		1	1			
1133930	1	1	1		1	1		1	1			

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133931	1	1			1	1		1	1	1		
1133932	1	1			1	1	1	1	1	1		
1133933	1		1	1	1	1		1				
1133934	1	1	1		1	1						
1133935	1	1			1							
1133936	1	1		1	1	1		1				1
1133937	1	1	1		1	1	1	1	1		1	
1133938	1				1	1		1	1	1		
1133939	1				1	1		1				
1133940	1			1	1	1		1				
1133941	1	1	1		1	1	1	1	1	1		
1133942	1				1	1		1	1	1		
1133943	1	1	1		1	1		1				
1133944	1				1	1		1				
1133945	1	1		1	1	1		1			1	1
1133946	1	1	1		1	1		1	1	1		
1133947	1			1	1	1		1				1
1133948	1	1			1	1		1			1	1
1133949												
1133950	1	1		1	1	1		1				1
1133951	1	1			1	1	1	1	1			
1133952	1			1	1	1		1				
1133953	1			1	1	1		1				
1133954	1			1	1	1		1				
1133955	1				1	1		1				
1133956	1			1	1	1		1				1
1133957	1	1	1		1	1	1	1	1			
1133958	1	1	1		1	1		1	1	1		
1133959	1	1			1	1		1	1	1		
1133960	1	1		1	1	1		1				1
1133961	1	1			1	1		1	1	1		
1133962	1				1	1		1	1			

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133963	1	1			1	1	1	1	1	1		
1133964	1				1	1		1				1
1133965	1			1	1	1		1				
1133966	1	1		1	1	1	1	1				
1133967	1				1	1						
1133968	1			1	1	1		1			1	
1133969	1				1	1		1	1	1		
1133970												
1133971	1	1			1	1		1	1			
1133972	1	1			1	1		1				
1133973	1			1	1	1		1				
1133974	1	1		1	1	1		1				1
1133975	1				1	1	1	1	1	1		
1133976	1		1		1	1		1	1			
1133977												
1133978	1	1			1	1						
1133979	1	1	1		1	1		1	1			
1133980	1				1	1	1	1	1	1		
1133981	1	1			1	1	1	1	1			
1133982	1	1			1	1	1	1	1	1		
1133983	1	1	1		1	1	1	1			1	
1133984	1	1		1	1	1	1	1				
1133985												
1133986	1	1			1	1	1	1	1			
1133987	1	1		1	1	1		1				1
1133988	1			1	1	1		1				
1133989	1	1			1	1	1	1	1	1		
1133990												
1133991	1	1		1	1	1		1				
1133992	1	1			1	1	1	1	1	1		
1133993												
1133994	1				1	1		1	1			

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1133995	1	1		1	1	1		1				
1133996	1	1	1		1	1	1	1	1	1		
1133997	1				1					1		
1133998												
1133999												
1134000	1	1			1	1		1	1			
1134001	1	1		1	1	1		1				
1134002	1	1			1	1	1	1	1	1		
1134003	1	1	1		1	1		1	1			
1134004	1	1			1	1		1	1			
1134005												
1134006	1	1			1	1						
1134007	1				1	1		1	1			
1134009	1			1	1	1		1				
1134010	1	1	1	1	1	1		1			1	
1134011												
1134012	1		1		1	1	1	1	1	1		
1134013	1	1	1		1	1		1				
1134015	1	1	1		1	1	1	1	1	1		
1134016	1	1			1	1		1	1	1		
1134017	1			1	1	1		1				
1134018	1	1			1	1	1	1	1	1		
1134019	1	1		1	1	1	1	1			1	
1134020	1	1		1	1	1		1				1
1134021	1	1	1		1	1	1	1	1			1
1134022	1				1	1						
1134023	1			1	1	1		1			1	1
1134024	1	1			1	1	1	1	1			
1134025	1	1		1	1	1		1				
1134026	1		1		1	1	1	1				
1134027	1				1	1	1	1	1			
1134028	1	1	1		1	1		1	1			1

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1134029	1	1			1	1		1	1	1		
1134030	1	1	1	1	1	1		1			1	1
1134031	1				1	1		1				
1134032												
1134033	1	1		1	1	1		1				1
1134034												
1134035												
1134036	1		1	1	1	1		1				1
1134037	1		1		1	1		1	1			
1134038	1				1	1		1	1	1		
1134039	1	1			1	1	1	1	1	1		
1134040	1	1			1	1	1	1	1	1		
1134041	1	1	1		1	1		1	1			
1134042	1	1			1	1		1	1			
1134043	1	1	1		1	1		1				
1134044												
1134045	1				1	1						
1134046	1	1	1		1	1		1	1	1		
1134047	1	1			1				1	1		
1134048	1				1	1						
1134049	1	1			1	1		1	1			
1134050	1				1	1		1				
1134051	1				1	1						
1134052	1	1		1	1	1		1			1	1
1134053	1	1		1	1	1		1			1	
1134054	1	1	1		1	1		1				
1134055												
1134056	1	1			1	1		1			1	1
1134057	1	1			1				1	1		
1134058	1	1		1	1	1		1				
1134059	1				1	1		1	1			
1134060	1				1	1						

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1134061	1			1	1	1		1				
1134062												
1134063	1	1			1	1		1	1			
1134064	1		1	1	1	1		1				
1134065												
1134067												
1134068	1	1			1	1		1	1		1	1
1134069	1				1	1		1	1	1		
1134070												
1134071	1				1	1	1	1	1	1		
1134072	1		1	1	1	1		1			1	
1134073	1	1			1	1	1	1	1	1		
1134074	1				1	1						
1134075	1	1			1	1	1	1			1	1
1134076	1	1			1	1		1	1	1		
1134077	1				1	1						
1134078	1				1	1						
1134079	1	1		1	1	1	1	1			1	
1134080	1	1	1		1	1		1	1		1	
1134081	1			1	1	1		1				1
1134082	1				1	1		1				
1134083												
1134084	1	1			1	1		1	1	1		
1134085	1				1	1		1	1	1		
1134086	1	1			1	1	1	1	1			
1134087	1				1	1		1				
1134088												
1134089	1				1	1		1	1	1		
1134090	1	1			1	1	1	1	1			
1134091	1		1		1	1	1	1	1	1		
1134092	1				1	1						
1134093	1	1			1	1		1				

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1134094	1	1			1	1		1				
1134095	1	1			1	1		1	1	1		
1134096	1				1	1		1	1			
1134097	1				1	1		1				
1134098	1				1	1						
1134099	1				1	1						
1134100	1	1	1	1	1	1		1				
1134102	1	1			1	1		1	1	1		
1134103	1	1			1	1		1				
1134104	1	1	1	1	1	1		1				
1134105	1	1	1		1	1	1	1	1	1		
1134106	1	1			1	1		1	1	1		
1134107	1	1			1	1		1				
1134108	1				1	1		1				
1134109	1	1	1		1						1	1
1134110	1	1	1	1	1	1		1	1			
1134111	1	1	1	1	1	1		1			1	1
1134112												
1134113	1	1			1	1		1	1			
1134114	1	1	1	1	1	1		1			1	1
1134115	1	1	1	1	1	1		1				1
1134116	1		1	1	1	1		1				
1134117	1	1			1	1	1	1				
1134118	1	1			1	1		1	1	1		
1134119												
1134120	1	1		1	1	1		1				
1134121	1				1	1						
1134122	1	1	1		1	1	1	1	1	1		
1134123												
1134124	1				1	1		1				
1134127	1				1	1						
1134128	1	1			1	1		1	1			

Crosswalk Table of Tag and Dependent Analysis												
Fish ID	**4.1.1 - 4.1.5**	**4.1.6 [3D]**	**4.1.6 [7D]**	**4.1.7**	**4.1.8**	**4.2.1 & 4.2.2**	**4.2.3**	**4.3.1 [TC]**	**4.3.1 [CC]**	**4.3.1 [MR]**	**4.3.2**	**4.3.3**
1134129	1				1	1		1	1			
1134130	1	1		1	1	1		1			1	1
1134131	1	1		1	1	1		1				
1134132	1	1			1	1	1	1	1	1		
1134133	1	1			1	1		1	1			
1134134	1			1	1	1		1				
1134135												
1134136	1		1		1	1		1				
1134137	1				1	1		1	1	1		
1134138	1	1		1	1	1		1				
1134139	1	1		1	1	1		1				
1134140	1	1			1	1	1	1	1			
1134141	1	1			1	1		1	1	1		
1134142												
1134143	1	1			1	1		1				
1134144	1	1			1	1		1	1	1		
1134145												
1134146	1	1			1	1						
1134147	1	1		1	1	1		1				
1134148												
1134149	1	1			1	1		1	1	1		
1134150	1	1			1	1		1				
1134151	1	1			1	1		1	1	1	1	1
1134152	1				1	1						
1134153	1	1		1	1	1		1				
1134154	1	1	1		1	1						
1134155	1	1			1	1	1	1	1	1		
1134156	1	1			1	1	1	1	1	1		
1134157	1	1	1		1				1	1		
1134158	1	1	1		1	1		1	1			
1134159	1				1							
1134160	1	1		1	1	1		1			1	1

Crosswalk Table of Tag and Dependent Analysis

Fish ID	4.1.1 - 4.1.5	4.1.6 [3D]	4.1.6 [7D]	4.1.7	4.1.8	4.2.1 & 4.2.2	4.2.3	4.3.1 [TC]	4.3.1 [CC]	4.3.1 [MR]	4.3.2	4.3.3
1134161	1	1	1		1	1		1			1	
1134162	1	1			1	1		1	1	1		
1134163												
1134164	1	1			1	1		1				
1134165	1	1		1	1	1		1				
1134166	1	1			1	1						
1134167	1	1			1	1	1	1	1	1		
1134168												
1134169	1				1	1		1	1			
1134170	1	1		1	1	1		1				
1134171												
1134172												
1134173	1	1	1	1	1	1		1			1	
1134174	1				1				1			
1134175	1		1		1	1	1	1	1			1
1134176	1				1	1						
1134177	1				1	1		1	1			
1134179	1	1			1	1		1				
1134180	1				1	1	1	1	1			
1134181	1	1			1	1	1	1	1	1		
1134182	1	1		1	1	1		1			1	1
Total	447	276	144	131	447	435	89	391	197	120	50	75